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THE GREEN SCHISTS AND ASSOCIATED GRANITES AND PORPHYRIES OF RHODE ISLAND

BY

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ILLUSTRATIONS.

THE GREEN SCHISTS AND ASSOCIATED GRANITES AND PORPHYRIES OF RHODE ISLAND.

By B. K. Emerson and J. H. Perry.

INTRODUCTION.

SCOPE OF PAPER.

A great mass of coarse, porphyritic granitoid gneiss occupies the towns of Sutton, Northbridge, and Douglas, in Massachusetts, and extends southward across western Rhode Island to Kingston, on the Sound, just west of the territory to be described in this bulletin. A series of quartzites and hornblendic rocks wraps round the northern part of this mass, resting on it unconformably with a very sinuous boundary. These two groups of rocks—the first called the Northbridge gneiss, the second made up of the Grafton quartzite and the Marlboro formation—may be assigned with considerable probability to the pre-Cambrian and Cambrian, respectively.

The continuity of the Cambrian rocks is greatly interrupted in Massachusetts by broad areas of intruded granite, and farther south, in the region here studied, only broad, isolated patches of the sedimentary rocks appear, like ice floes on a pond, in a confluent expanse of various eruptives, which differ in age and in lithologic character. This paper is devoted principally to a discussion of such of these interesting Cambrian remnants as lie within the limits of the State of Rhode Island and to a description of the associated eruptives, especially the remarkable series of very fresh porphyritic rocks that extend westward from the town of East Greenwich. The field work occupied three summers and covered the crystalline area along the western border of the Carboniferous rocks in the Providence and Narragansett Bay quadrangles. The work was undertaken for the purpose of publication in folios of the Geologic Atlas of the United States, but as the publication of the folios has been deferred and as the results of the survey are needed in the explanation of the structure of the territory adjacent on the north, in which work is now in progress, they are here presented in the form of a bulletin.

PREVIOUS WORK IN THE REGION.

The rocks studied comprise the western border of the Carboniferous of the Narragansett basin in Rhode Island and the more highly metamorphosed varieties of the Carboniferous rocks that extend over the older rocks. The results presented therefore supplement those contained in the monograph on the geology of the Narragansett basin by Shaler, Woodworth, and Foerste,[a] in which these rocks were not discussed. The bibliography of the Cambrian and Carboniferous rocks of the basin given in that volume[b] includes nearly every publication that makes allusion to the region here described. The report on the geology of Rhode Island by Dr. C. T. Jackson[c] is the fullest account of this region that has been written. The area considered in this bulletin is represented in green and blue on Doctor Jackson's map, where it is labeled "hornblende rock and limestone" and referred to the Primary. Not the least interesting of the early writings on this region is the very clear description given by Prof. Ebenezer Emmons,[d] in which he assigns the green schists to the Taconic—that is, to the Cambrian (the age of the Stockbridge limestone)—and finds several members of the "Taconic system" represented here. He gives an accurate section across the area from southwest to northeast through the limestone quarry. Prof. W. O. Crosby, as the result of a brief visit to the region thirty-five years later, describes the rocks and assigns them doubtfully to the Huronian and Montalban.[e]

TABLE OF FORMATIONS.

The rocks in the area investigated are tabulated below, the table beginning with the oldest:

Formations in the Narragansett basin.

EARLIEST ROCKS:
- Pre-Cambrian.
  - Northbridge gneiss.

SEDIMENTARY ROCKS:
- Cambrian.
  - Grafton quartzite.
    - Albion schist member.
  - Marlboro formation, including green schists, amphibolite, mica schist, and, as a subordinate member, the Smithfield limestone, which changes into tremolite schist, steatite, and serpentine.

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[a] Mon. U. S. Geol. Survey, vol. 33, 1899.
[b] Idem, p. 212.
[c] Jackson, Charles T., Report on the Geological and Agricultural Survey of the State of Rhode Island, 1839. Published in 1840.
[d] Emmons, Ebenezer, Agriculture of New York, vol. 1, 1846, pp. 91-93.
[e] Crosby, W. O., Contributions to the Geology of Eastern Massachusetts, 1880, pp. 127-128.

SEDIMENTARY ROCKS—Continued.
- Carboniferous.
  - Unaltered rocks.
    - Shale.
    - Conglomerate.
  - Metamorphosed rocks.
    - Biotite-spangled phyllite.
    - Chloritoid-spangled phyllite.
    - Arenaceous chloritoid schist.
    - Magnetitic mica schist.
    - Conglomeratic mica schist.

IGNEOUS ROCKS:
- Cambrian.
  - Diorite.
- Post-Cambrian (pre-Carboniferous).
    - Milford blue-quartz granite.
    - Aplite.
    - Gabbro.
    - Odinite.
    - Cumberlandite.
- Early Carboniferous or late pre-Carboniferous.
  - Quincy group.
    - Porphyritic granite.
    - Granite porphyry.
    - Riebeckite porphyry.
    - Microgranite.
    - Hornblende granite.
  - East Greenwich group.
    - Granite.
    - Granite porphyry.
    - Blue-quartz porphyry.
    - Microgranite.
    - Graphic microgranite.
    - Graphic microgranite and granite-porphyry breccia.
- Post-Carboniferous.
  - Olivine-diabase porphyry.
  - Porphyritic diabase.

PRE-CAMBRIAN ROCKS.

NORTHBRIDGE GNEISS.

Northbridge gneiss is the name given elsewhere[a] to the great area of pre-Cambrian gneiss that extends southward from Southboro, Mass. A rock having all the characteristics of the Northbridge gneiss and forming its probable southward extension occupies the southwest corner of the area mapped in Pl. I. It is a medium- to coarse-grained granitoid gneiss, of light color, containing smoky quartz in long pencils. The feldspar, the most abundant constituent of the rock, presents a notable contrast with the quartz in being regularly and evenly granular. The grains are just visible to the eye. Bladed biotite, magnetite, and a little muscovite appear. The rock crumbles into a

[a] Emerson, B. K., Geology of old Hampshire County: Mon. U. S. Geol. Survey, vol. 29, 1898, p. 18.

mass of pencils, as does the gneiss in Northbridge, Mass. It grows coarser and porphyritic toward the west. The distinction here, as in Massachusetts, between a coarser, less crushed, and porphyritic facies and a finer, more schistose, and more completely mashed and stretched facies is noted on the map.

The connection of the rock of this area with the Northbridge porphyritic granite-gneiss has not been definitely traced in the field, but is very probable, since Jackson[a] described the rock as of wide extent across Kingston and represented it on his map at many points in West Greenwich, Coventry, and Foster, and we have traced it southward from Douglas, Mass., across Burrillville into Glocester, R. I., the town adjoining on the west the area here considered.

The porphyritic granite-gneiss that borders the Cambrian on the south and east of the Carboniferous rocks of the Narragansett basin, as, for example, around Conanicut, Newport, and Little Compton, would seem to be of the same age as the Northbridge gneiss if the contention of Dale is correct, that it is an older member underlying the Cambrian. Pirsson,[b] Crosby and Barton,[c] and Foerste[d] are, however, certain that this granite-gneiss cuts the Cambrian and is thus the newer rock, and in this case it is probably of the same age as the Milford granite.

The least stretched varieties of the Northbridge gneiss and the most crushed facies of the Milford granite are indistinguishable at some places in the field. The Northbridge gneiss is characterized by a coarse-meshed microcline, which is replaced in the Milford granite by a complex microperthite, the albitic constitutent of which is centrally dusted with epidote.

CAMBRIAN ROCKS.[e]

SUBDIVISIONS AND NOMENCLATURE.

The Cambrian rocks, as they appear along the Blackstone Valley between Woonsocket and Pawtucket, are described in this text and shown on the geologic map (Pl. I) under four subdivisions:

1. A central band of phyllite and fine-grained micaceous quartz schist—the Albion schist member.

2. Two flanking bands of a granular massive quartzite—the Grafton quartzite.

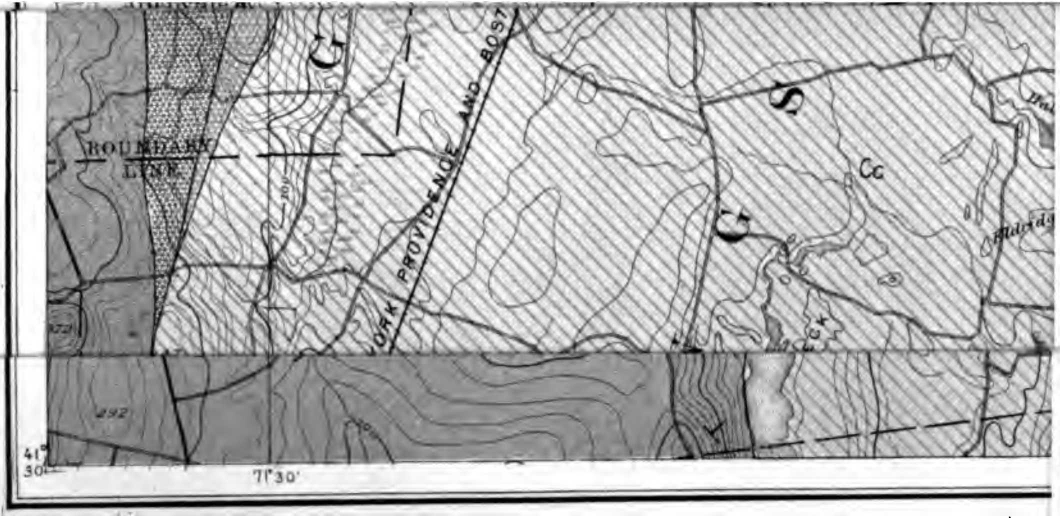
[a] Jackson, Charles T., Report on the Geological and Agricultural Survey of the State of Rhode Island, 1839. Published in 1840.

[b] Pirsson, L. V., On the geology and petrography of Conanicut Island, R. I.: Am. Jour. Sci., vol. 46, 1893, pp. 363-378.

[c] Crosby, W. O., and Barton, G. H., On the great dykes at Paradise, near Newport: Proc. Boston Soc. Nat. Hist. (1886), vol. 33, p. 325.

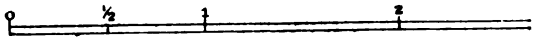
[d] Shaler, N. S., Woodworth, J. B., and Foerste, A. F., Geology of the Narragansett basin: Mon. U. S. Geol. Survey, 1899, vol. 33, p. 235.

[e] "Blackstone series" of Woodworth.



Henry Gannett, Chief Geographer.
Marcus Baker, Geographer in charge
Triangulation by the U.S. Coast and Geodetic Survey
and R.U. Goode
Topography by Wm. Kramer, S.H. Bodfish, E.B. Clark,
E.W.F. Natter, and J.H. Jennings
Surveyed in 1885, 1887, and 1888.

Scale



Contour interval 20 feet
Datum is mean sea level
1906.

MAP OF THE CRYSTALLINE ROCKS IN THE VICIN
PROVIDENCE AND NARRAGANSETT BAY
RHODE ISLAND

3. Two broad exterior bands of green schists and amphibolite—the Marlboro formation.

4. Thick beds of crystalline limestones with soapstone and serpentine in the sediments—the Smithfield limestone.

This series of rocks in Massachusetts was several years ago traced southward by the senior author of this paper[a] from Westboro (where the quartzite and amphibolite appear in typical development) with a good degree of continuity to the area here considered, and the names then proposed for them are here retained. Mr. Woodworth briefly touched upon the same rocks in connection with his description of the adjacent Carboniferous basin,[b] and proposed for them the name "Blackstone series." He gave the name "Cumberland quartzite" to the quartzose beds, and the name "Ashton schists" to the schistose beds. As we have found that the schistose beds are divisible, the name "Albion schist" is applied to the central quartz phyllite and mica schist upon which the village of Albion stands, and the larger group of green schists, amphibolites, soapstones, and limestones are called the Marlboro formation, from their equivalent farther north.

STRUCTURE.

The whole series occurs in several elongate patches which are inclosed in a great granite batholith on all sides up to the point where they are in contact with the Carboniferous. All its members have a uniform steep dip to the east. We can not tell whether the two broad bands of green schist that flank the central quartzite band are joined above the quartzite as a closed and overturned anticline, or beneath in synclinal arrangement. If our correlations are right, the green schists are probably the younger, as the hornblende schists of the Marlboro formation seem somewhat higher than the quartzites. At the south end of the isolated area of green schist north of Albion everything indicates that the green schist is the newer rock. The fact that the pebbles found in the green schists are of a quartzite like that of the central quartzite indicates that the green schists are the newer and that the structure is therefore anticlinal. The Providence area may be taken as a more irregular anticline of the quartzite flanked by the green schists, and, like the other, included in the Milford granite.

The dips and strikes given on the map (Pl. I) show the probable posture of the beds in the middle of the Cumberland area. The isolated central area of the green schist on the Albion schist makes it probable that it is a passage bed between the Grafton quartzite and the Marlboro formation.

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[a] Mon. U. S. Geol. Survey, vol. 29, 1898, p. 18.
[b] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 106.

and we have in a later section attempted to connect this formation with the similar ferruginous and calcareous Cambrian beds at North Attleboro. The more massive rocks, which most simulate eruptives, are the thick beds of tremolitic steatite and serpentine derived from limestone. A large slab of the conglomeratic green schist from a ledge on the top of the hill 100 rods north of the middle quarry at Lime Rock contains many well-rounded pebbles of a very fine-grained white-bleaching actinolitic quartzite like the finest beds of the Albion quartzitic schist; also many pebbles of coarser and finer varieties of a diorite which appears in a considerable mass in the same hill. This makes it certain that a part of the ferruginous material of the green schist is tuffaceous and related to these diorites. Before we made this discovery we had regarded the few occurrences of this diorite as eruptive. They occupy but a small area, and the hornblendic beds of the green schist proper are of a different and plainly metamorphic clastic type.

The aphanitic quartzite pebbles are unlike the coarse saccharoidal Grafton quartzite, but resemble the fine-grained calcareous quartzite of the green schist series itself, especially that form of it seen in inclosures in the porphyry in Cumberland; that is, the actinolite quartzite is such a rock as would be produced if the calcite of the latter rock had gone to the formation of abundant actinolite needles.

The interesting relations of this tuffaceous conglomerate and the adjacent diorite are discussed on page 44.

VARIETIES OF THE SCHIST.

Epidote-chlorite schist.—A typical green schist outcrops by the roadside a mile northwest of Lonsdale, near the granite. It is a fine-grained, irregularly fissile schist of gray-green color, with indistinct green veinlets of a shade suggesting pistachio green. There are minute perfect crystals of pyrite (100) (111), superficially changed to limonite. The sheen of a micaceous mineral can be seen. The veins alone give slight effervescence with cold acid. The slide (362) shows with the lens porphyritic rounded spots, around which the constituents have a somewhat concentric arrangement. The field shows a dense mat of elongate green (chlorite) and pale-green (actinolite) blades with a few small, angular, colorless grains of quartz, more or less strained, the whole being dusted with a shining, granular, almost colorless mineral (epidote). The chlorite is uniaxial and positive (pennine), with pleochroism ranging from yellow-green to emerald-green.

Some of the porphyritic spots are relics of plagioclase phenocrysts, now almost wholly changed to groups of small, stout epidotes and olive-green biotites. One of the plagioclase remnants gave extinction 13–13, with broad bands. These feldspars are rare and are irregularly distributed. They may have been derived from diorite grains in the

tuff. The granular mineral shows red of the second order in a slide of normal thickness, and so is epidote rather than zoisite.

Another rock from the same locality is a similar green, mottled, very fine-grained schist or slate, with large chalcopyrite grains surrounded by a rim of just visible hornblende needles. The slide (370) is a mat of very fine-grained hornblende needles with blue absorption on c and chlorite scales in a clastic ground, with much epidote and many wisps of fasciculate tourmaline needles, with very strong absorption, salmon-colored parallel to c, blue-black parallel to a.

Actinolite quartzite.—A fine-grained massive rock, varying from white to dark gray, occurs as pebbles in the tuffaceous conglomerate and in independent beds. It is made up wholly of very fine grains of angular quartz and of needles of pale-green actinolite, the latter being in places abundant.

Chlorite-actinolite schist.—Another rock collected at a place one-third of a mile from the granite and one-half mile west of Woodville, in West Providence, was the common, greenish-black, fissile rock, showing with the lens stout, minute actinolite needles and chlorite scales. The slide (437) showed abundant broad blades of chlorite and actinolite with ragged ends, which form an open network in a ground made up of magnetite and epidote grains and minute actinolite needles.

Hornblende schist.—Hornblende schist is especially abundant in the green schist around the Lime Rock limestone and east of the river in the land west of Sneech Pond about Cumberland Hill, which is marked hornblende rock on Jackson's map. There is at Smithfield a beautiful satiny, thin-fissile amphibolite, made up of brilliant black needles pointing in a common direction.

Doctor Jackson's remarks concerning the hornblende rock are extremely interesting and show that the doubts about its origin arose early (1839).

> The rock * * * presents some of the most perplexing geological enigmas that have fallen under my notice. It is generally regarded as an unstratified rock of igneous origin, but not unfrequently presents the appearance of regular stratification. * * * It passes frequently by imperceptible shades into chloritic and argillaceous slates, so that it is very difficult to define its exact limits. * * * I am of opinion that it is decidedly a rock of igneous origin; * * * that it derives its occasionally stratiform structure from an admixture of argillaceous slate rock through which it was elevated * * * and * * * that the serpentine frequently is a product of the interfusion of the hornblende rock and the soapstone. * * * It is highly probable that * * * the hornblende rock has charged the Smithfield limestone near its junction with magnesia.[a]

It will be noted that we assign a part of Doctor Jackson's hornblende rock to an igneous origin and part to a sedimentary and metamorphic origin. His last three propositions we should hardly indorse, though we made no study of the dolomite in the Smithfield limestone.

[a] Rept. Geol. and Agr. Survey of Rhode Island, 1840, pp. 30-31.

SMITHFIELD LIMESTONE MEMBER.

GENERAL FEATURES.

The great "Harris" and "Dexter" beds of limestone in Lincoln (formerly part of Smithfield, from which the name Smithfield limestone is derived) have long been known because of their economic importance and the interesting minerals found in them. They have given name to the village of Lime Rock and still sustain a considerable industry, although they are less important than they were before the advent of the railroad.

Formerly many other beds were worked that are now abandoned, for large beds of this rock occur in many parts of the Marlboro formation, and those now found are only a part of the limestone which was present in the original rock. Many beds of tremolite rock, soapstone, serpentine, amphibolite, and ores of iron and copper have replaced limestone. In color the rock is generally pure white, but is in some places banded in dark gray or tinged yellow with iron or pink with manganese, as if it contained rhodochrosite.

The Smithfield beds vary from massive saccharoidal marbles of fine to above medium grain to rocks laminated through shearing with the development of chlorite, asbestos, mountain leather, and talc upon the gliding planes. Professor Woodworth figures the echeloned fragments of a disjointed dike in the limestone in the southern bed in Lincoln, and calls attention to the fact that the limestone has under pressure flowed into all the interstices and now shows no trace of the separation.[a]

These beds are plainly the contemporaneous members of a sedimentary series intercalated originally with clayey, marly, and tuffaceous layers. They attain in places a thickness of 150 feet or more, and their present appearance in isolated, long, elliptical masses is due to faulting, solution, and the metamorphism of much of the original limestone into other rocks. They are in part dolomitic and in part pure limestones.

They have been in many places replaced by ores of iron and copper, especially at Copper Mine Hill, north of Sneech Pond, in Cumberland. Doctor Jackson says:[b]

> The magnesium limes of Rhode Island have always ranked high in the estimation of masons, and they are prized for the quickness of their setting when converted into mortar, as also for the beautiful whiteness of the lime. Hence the Smithfield "hard-jointer" rock, being a magnesium limestone, makes a variety of lime that commands a higher price in the market than any other. This kind of lime is, however, unfit for agriculture, and care should be taken to use only the soft rock for that purpose, since it is free from magnesia.

The dolomite of Rhode Island is that portion of the bed which lies in contact with or near the hornblende rock. In some places, however,

[a] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 108.

[b] Jackson, idem, p. 36.

the line of dolomitization appears to terminate abruptly at a distance of 6 or 10 feet from the hornblende rock.[a]

The figures given below show the annual value of the lime burned in Rhode Island, the industry being confined almost entirely to Providence County.[a]

Value of lime produced in Rhode Island, 1890–1905.

1890	$27,625	1898	$10,215
1891	25,000	1899	18,239
1892	30,000	1900	16,715
1893	24,800	1901	37,798
1894	20,433	1902	
1895		1903	34,432
1896	11,589	1904	31,871
1897	11,555	1905	42,743

The following table of analyses is taken from Doctor Jackson's report.[b]

Analyses of limestones from Rhode Island.

No.	Locality, owner, etc.	Variety.	Carbonate of lime.	Insoluble matter.	Oxide of iron.	Magnesia.	Lime.	Specific gravity.
1	Cumberland Hill, F. Brown.	White, greenish, granular.	52.2	6.0	....	40.6	29.4	2.728
2	Cumberland Hill	Greenstone (8.0 water)	68.8	23.2	1.0	6.2	38.7	....
3	Johnston, Mr. Brown.	Stone, white with yellowish spots, crystalline.	55.2	46.6	....	4.2	31.1	....
4	Johnston, Mr. Jenkins.	Stone, white with yellowish and green spots, crystalline.	97.2	.8	....	.6	54.6	....
5	North Providence	White, compact, subcrystalline.	56.1	11.4	....	32.5	31.6	....
6	Newport Harbor, Lime Islands.	Compact, blue and buff colored.	53.2	7.0	1.9	37.9	29.9	2.824
7	North Providence, lime quarry.	White and compact	68.6	8.6	....	21.0	38.6	....
8	Smithfield, Harris rock.	Rhomb spar	92.8	....	3.8	3.4	52.2	....
9	Shore near Fort Adams.	Yellow, buff-colored, compact.	50.9	4.3	2.1	42.7	28.7	2.822
10	Smithfield, Harris quarries.	Soft rock	92.4	6.0	.4	1.2	52.0	....
11	Smithfield, Harris rock.	First quality hard rock.	60.4	1.0	2.6	36.0	34.0	....
12	Smithfield, Dexter quarry.	White, granular, and crumbly.	94.8	1.6	....	....	53.4	2.660
13	.....do	Compact, white, insoluble matter in acicular crystals.	64.6	2.0	Tr.	32.0	36.4	2.853
14	Smithfield, S. Arnold.	Stone, white, coated with talc and crystalline.	50.6	3.8	Tr.	44.4	28.5	....
15	Smithfield, Harris quarry.	First quality soft blue stone with blue and white stripes, crystalline.	92.2	1.0	....	6.8	51.9	....
16	Smithfield, Harris rock.	Crystalline and granular.	95.8	1.4	....	2.8	58.0	2.681
17	.....do	Very clear light blue stratified and crystalline.	87.0	12.4	....	....	49.0	2.715
18	Smithfield, E. Angell.	Stone white and crystalline.	97.6	1.0	....	....	54.9	....

[a] Twenty-first Ann. Rept. U. S. Geol. Survey, 1899, pt. 6 (continued), pp. 357–360; Mineral Resources U. S. for 1901, p. 667.

[b] Idem, p. 246.

The following analysis of the limestone quarried by Mr. Herbert Harris at his quarry at Lime Rock, Providence County, was made by Prof. J. H. Appleton, of Brown University.[a]

Analysis of limestone quarried at Lime Rock, R. I.

Moisture	0.040
Oxide of iron	.011
Alumina (Al_2O_3)	.309
Siliceous matter (insoluble)	2.748
Calcium carbonate ($CaCO_3$)	88.233
Magnesium carbonate ($MgCO_3$)	8.797
	100.138

DETAILED DESCRIPTIONS OF THE LIMESTONE BEDS.

ORES OF COPPER, MANGANESE, AND IRON.

On Doctor Jackson's map the symbol for copper is repeated several times in the area northwest of Sneech Pond. Reporting upon this area he says that[b] the limestone in the beds at Cumberland Hill, on the estate of Mr. F. Brown, runs N. 25° W., dips 35° E., and is 6 to 10 feet thick and dips beneath the granite. He states that it contains copper pyrites, tremolite, asbestos, and actinolite, and a number of curious minerals common to such limestones.

Continuing he writes:

Near Sneech Pond there is an ancient mine, sunk apparently for the purpose of extracting ores of copper, which are found there mixed with veins of granular magnetic iron ore. The shaft slopes to the northeast by east, following the dip of the vein, and is 20 to 30 feet wide, but it has for a long time been filled with water, so that its depth has not been ascertained.

Near the pond occurs a very thick bed of a remarkable ore of manganese, which is peculiar in its composition, but most nearly resembles the knebelite of Beudant. The bed is no less than 40 feet thick, and when any method of making use of the mineral is discovered it may prove an important locality. One hundred grains of this mineral were taken for analysis, and the following results were obtained:

Silicic acid	26.400
Protoxide iron	35.912
Protoxide manganese	32.488
Carbonic acid	5.200
	100.000

Another specimen yielded:

Silicic acid	29.400
Protoxide iron	37.707
Protoxide manganese	27.692
Carbonic acid	5.200
	99.999

Specific gravity mean of three specimens, 3.7881.

[a] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6 (continued), p. 442. [b] Idem, pp. 54-56.

Associated with this mineral occur crystals of green quartz, or prase, and veins of quartz penetrated by delicate green crystals of actinolite, forming a kind of ornamental stone for which the name Thetis Hair stone has been proposed. Sulphuret of molybdena also occurs in the manganese ore, and the yenite formerly discovered near this place is said to have been formed in the accompanying quartz veins. Ligneous actinolite abounds in the veins with the quartz above mentioned.

Several excavations of considerable extent have been made in this vicinity, and were probably prompted by the discovery of masses of yellow copper pyrites, which was doubtless mistaken for gold, as it generally is by persons unacquainted with mineralogy. It is worth remarking that there are no less than 50 different ancient mine holes in this hill, and it is estimated that more than half a million dollars must have been spent in these fruitless researches for the precious metals. The iron ore appears to have been generally neglected, although when wood was abundant in this vicinity it might have been profitably wrought for iron.

At one of these ancient mines it was easy to discover what minerals were sought for, since one of the casks in which the ore had been packed for the purpose of sending it to England had been left, and from its broken and partly decomposed staves we picked up an abundance of the yellow copper pyrites which is found accompanying the granular magnetic iron ore. I took a fair specimen of this ore and subjected it to separation by the magnet, and then reduced the copper ore which was left. It contains, in 100 grains of the picked ore:

Copper	36.842
Iron	31.940
Sulphur	31.218
	100.000

Professor Woodworth reports that angular brecciated fragments of the limestone lie in the ore-bearing mass at this locality, and assumes that the ores of iron and copper have replaced the limestone, as is doubtless the case. He mentions that there are eruptive rocks near, but finds no means of determining whether the ore has been deposited through the action of heated waters connected with these eruptives or through the downward percolation of acidulated surface waters. Fluorspar in small quantity everywhere accompanies the eruptives, and we should expect to find it concentrated in considerable abundance in the ores if these were produced from solutions derived from the vicinity of these eruptives, and such we found to be the case.

Epidote occurs south of the road a mile east of Sneech Pond, in masses a foot thick, in the green schist doubtless derived from the alteration of small limestone beds.

NONOCCURRENCE OF ILVAITE IN RHODE ISLAND.

The citation of yenite, above, depends upon a determination in 1823 by Prof. C. U. Shepard[a] of a mineral having apparently all the properties of yenite. This mineral was found on Tower Hill, in Cumberland, in a matrix of quartz, epidote, and magnetite. Dr. Samuel Robinson cites the same mineral "1 mile east of Cumberland meeting-house, associated with calcareous spar, actinolite, quartz, and prase."[b]

[a] Am. Jour. Sci., vol. 7, 1824, p. 251.

[b] Am. Jour. Sci., vol. 8, 1824, p. 231.

Professor Shepard describes it in his Mineralogy[a] in 1832 and 1835 as traversing quartz in seams and as associated with magnetic iron and hornblende. In his third edition, in 1852, he omits the locality entirely, and in his collection there were no specimens from Rhode Island labeled yenite, but there were black crystals labeled knebelite. Neither is there a specimen labeled yenite in the second collection he formed, which came to Amherst College after his death. The citation has remained in Dana's Mineralogy from the beginning, but it should be canceled.

Professor Dana originally reported from Cumberland the minerals manganese, epidote, actinolite, garnet, titaniferous iron, magnetite, red hematite, chalcopyrite.[b] In the sixth edition E. S. Dana (1892) copied this list, with the additions of bornite, malachite, azurite, calcite, apatite, feldspar, zoisite, mica, quartz crystals, and ilvaite. At Beaconpole Hill he reports crocidolite; at Sneech Pond, chalcopyrite, ilvaite, wad, molybdenite, magnetite, epidote, and chlorite.

It is probable that the knebelite crystals from the manganese locality near Sneech Pond gave occasion for the incorrect citation given under ilvaite in each edition of Dana's Mineralogy, viz:

> Reported as formerly found at Cumberland, R. I., in slender black or brownish black crystals traversing quartz along with magnetite and hornblende.

It is remarkable also that knebelite is not entered in these lists from the report of Doctor Jackson, particularly as his citation is sustained by the two analyses quoted above, which agree well with other analyses of this mineral.

Mr. George F. Kunz writes as follows concerning gem stones found at Cumberland, R. I.:[c]

> The so-called Thetis hairstone described by Doctor Jackson, found at Cumberland, R. I., is really a quartz cat's-eye, and some very fair cat's-eyes have recently been cut from it by Mr. Edwin Passmore, one of them nearly two-thirds of an inch long, and quite equal to many from Hoff, Bavaria.
>
> The beautiful specimens of limpid milky quartz, and also quartz crystals, the latter at times from three-fourths of an inch to 2 inches long, are found penetrated by crystals of black hornblende varying in size from acicular to those one-sixteenth inch in diameter and at times 6 inches long. They interlace and penetrate the quartz in every direction, making a very beautiful gem and ornamental stone. Fine pieces 6 inches square have been found. It occurs at the quarry at Calumet Hill, Cumberland, R. I., where the workmen, as a rule, knowing its value, secure the best specimens for disposal to the greatest advantage. Some hundreds of pounds of this material were sent abroad a few years ago to be cut up for jewelry at Idar and Oberstein. As, however, work has been suspended at the locality the mineral is likely to become somewhat uncommon. Cut specimens sell at from 50 cents to $5, and specimens polished on one side at from 25 cents to $5. This locality is one of the best known for this association.

[a] Treatise on Mineralogy, pt. 2, 1832, p. 288.
[b] System of Mineralogy, 1883, p. 770.
[c] Kunz, G. F., Precious stones: Mineral Resources U. S., 1883–4, pp. 755, 761.

It is interesting to go back to what may be called the mineralogical period of geological science in America, initiated by the early volumes of the American Journal of Science, and read the first citation of the molybdenite mentioned above (p. 20) as it appeared in that journal under the heading "Miscellaneous localities of minerals,"[a] in an item by Dr. Samuel Robinson, of Providence, R. I., viz:

Sulphuret of Molybdena with *magnetic oxide of Iron* and *magnetic pyritous Iron* ½ a mile N. N. E. from C. M. H. [Cumberland meeting house], at a place called the "Mine Hole," on the west side of a Hill which overlooks "Sneerch's Pond," where a shaft was sunk for Copper 70 feet deep, 40 to 45 years ago.

INCLUSION OF LIMESTONE IN GRANITE PORPHYRY.

A remarkably interesting inclusion from the north end of the Cumberland granite-porphyry dike (slide 369) seems at first sight to be a gray penciled slate or fine sandstone, but is a nearly pure, granular limestone with a few muscovite, biotite, quartz, and magnetite grains.

Many of the grains are idiomorphic, and are brought by pressure into a direction parallel to a single line, so as to give the pencil structure. The forces gave motion in only one direction, as in the "drawing" of a wire. There are parallel bands of coaly matter in rounded grains, but no magnetite.

A similar inclusion (slide 361) from the same place is a light-gray, fine-grained, coarse columnar or penciled micaceous limestone, very impure, but effervescing freely. It contains many grains of pyrite, and weathers rusty and cavernous, as is usual with a calcareous rock. It is full of dark grains, which may be partly anthracite, in foliation bands which are thickly crowded on the contact. Much magnetite is present. There are many trains of strained quartz grains. Some seem surrounded by secondary growth.

The small degree of metamorphism in the limestones found in the large Cumberland dike is noteworthy. It would seem that they were involved in the porphyry when but little metamorphosed and that the porphyry acted on them at so low a temperature, and perhaps with so small an amount of water that it did not produce the most striking effects, especially failing to utilize the lime and iron to make actinolite or garnet or the lime to make tremolite. It is, indeed, possible that its inclusion in the porphyry has protected it somewhat from the long-continued crushing and circulation of heated waters to which the rest of the schists were subjected, so that the inclusions represent a stage before the development of actinolite, tremolite, garnet, epidote, and serpentine. Other fragments of the same rock, without being more metamorphosed otherwise, were soaked so full of fluorite from the mineralizing of the porphyry that they have a rich purple color.

[a] Am. Jour. Sci., 1st ser., vol. 8, 1824, p. 231.

HARRIS BED AT LIME ROCK.

The Harris bed is the largest bed of limestone and has been most extensively worked. It is at least 150 feet thick, and the present outcrops are the remnants of a more continuous band. It is largely a wholly massive, highly crystalline marble of rather fine grain and of snowy whiteness. It would be a very beautiful building stone, or would serve even as a statuary marble, if it were not so much fissured. Its fractured and broken structure has given it the name "jointer rock," by which it has long been known. Doctor Jackson says:[a]

It is included immediately in greenstone or hornblende rock of a dark brownish green color, compact in structure and exceedingly hard. * * * The Harris lime rock is largely wrought, it being considered the best quarry, and is usually known by the name of the jointer ledge, a name derived from the joints in the rocks. * * * That portion of the limestone which lies in contact with the hornblende rock is called the hard jointer, and is the variety of magnesian carbonate of lime called granular dolomite. About 10 feet from the hornblende rock the limestone graduates into pure granular carbonate of lime, occasionally colored with plumbaginous matter, oxides of manganese, and iron.

It is especially notable because of the dikes by which it is cut and the large number of interesting minerals which have been found in it.

Under the microscope the grains of calcite in some specimens are of coarse, even grain, and are rarely twinned. In other bands the calcite is crushed into a mass of elongate grains or finely powdered and many of the grains are twinned. The rock in some slides shows grains of colorless pyroxene and large plates of colorless hornblende broken up into separate fields by a growth of brightly polarizing talc, which itself merges into an aggregate of pale bluish plates of the colorless serpentine called bowenite. In other slides the rock contains much brown granular essonite. At its contact with the schist the limestone is tinted with malachite. Veins of a velvet-black, very greasy quartz run through the rock, and fine quartz crystals are found in the fissures.

The talc at the Harris quarry in Lime Rock is white, thin, and fissile, and some layers still effervesce with cold acid. It is derived from the tremolite, and inherits from it a matted fibrous structure. Tremolite, pure white asbestos, mountain leather, the pale-green serpentinous mineral "bowenite," and essonite are found at the eastern Lime Rock quarry. The last two are formed at the contact on the small dikes which cut the limestone.

Veins of compact epidote 3 inches thick occur in the white marble in Smithfield, and a similar rock made up of irregular alternating layers, about an inch thick, of dark-brown garnet and green epidote occur at Lime Rock. Similar epidote veins contain fragments of the black

[a] Idem, pp. 57, 58.

massive hornblende rock, which become so abundant in places as to form a breccia.

A pure white pyroxene occurs in the Lime Rock quarry, in coarse, radiate, columnar aggregates, the individuals of which are in some specimens developed in perfect crystals of the Nordmark type—100, 010, 001, 110, with parting parallel to 001. They are in prisms a half inch square, and resemble, even in the perfect basal parting, the canaanite from the Stockbridge marble.

The order of crystallization of the calcite in fissures in the limestone at Lime Rock is interesting. At first drusy surfaces of minute crystals having the form of the unit rhombohedron without modification were formed. These were calcite, as their effervescence with dilute acid shows. Upon this surface are perched simple forms—1/2 R and a very acuminate rhombohedron simulating a hexagonal prism. Upon this come scalenohedral forms of the greatest complexity. Some of these are flattened to resemble the half of one of the Egremont butterfly twins, or form square prisms with two opposite faces striated, and the two remaining faces polished. The corners of this apparently four-sided prism are replaced by the faces of an acute four-sided pyramid, producing an apparently quadratic form.

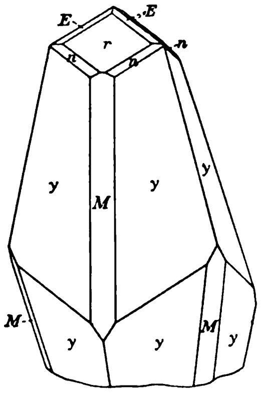

FIG. 1.—Calcite crystal from the Harris bed at Lime Rock.

Next an infiltration of limonite has covered the surface of the crystals with a tarnish of brilliant peacock colors. There has then followed a new growth of limpid calcite, which has placed upon the apex of the amber scalenohedra a capping having the form ∞P and —1. (See fig. 2.) Finally, rare needles of scolecite have grown in the drusy cavities. These are amber colored, transparent, and of the size of a fine hair, and have been bent in growing across the cavity. Only four of these delicate needles were found. One was found to be optically negative. Its greatest elasticity was parallel to its length, and a positive bisectrix emerges from the middle of one of its sides. It was decomposed by acid without effervescence. On revolution on the long axis the angle of extinction proved to be 7°.

Professor C. Palache has been so kind as to examine the calcite crystals and to send the following description and accompanying figures:

Fig. 1 shows the more important forms and the habit of most of the crystals. The dominant form is y, R 5, $3\ 2\ \bar{5}\ 1$, whose obtuse angles are truncated by the positive rhombohedron M, 4 R, $4\ \bar{4}\ 0\ 1$. The termination consists of r, R, $1\ 0\ \bar{1}\ 1$, with narrow planes of scalenohedrons of the principal zone, of which n, R 5/3, $4\ 1\ \bar{5}\ 3$, and E. 1/2R 5/3, $4\ 1\ \bar{5}\ 6$, are the commonest. e, —1/2R, $0\ 1\ \bar{1}\ 2$, is also sometimes present in the zone. M and r generally meet in a series of steplike oscillations not shown in the drawings.

Other steep scalenohedrons of the principal zone are also often present, sometimes in addition to y, sometimes taking its place. On one measured crystal the forms of this group found were as follows:

R 11/8, $19.3.\overline{22}.16$
n, R 5/3, $41\overline{5}3$
R 9/5, $72\overline{9}5$
R4, $53\overline{8}2$
R 16/3, $19.13.\overline{32}.6$
R6, $7.5.\overline{12}.2$
R 19/3, $11.8.\overline{19}.3$
R 20/3, $23.17.\overline{40}.6$

Fig. 2 shows an interesting parallel growth which was observed on one crystal. On a crystal of the ordinary habit is placed in parallel position a second consisting simply of the combination of prism of second order, a, ∞ P2, $11\overline{2}0$, and negative rhombohedron, e, −1/2R, $01\overline{1}2$.

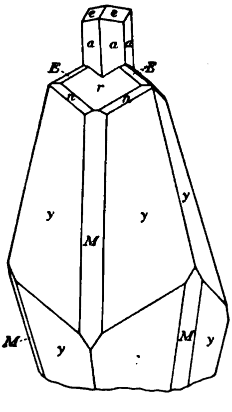

FIG. 2.—Calcite crystal from the Harris bed at Lime Rock. A later colorless addition is made to the golden yellow scalenohedron.

Another type of habit is illustrated in fig. 3. The forms are dominated by the same scalenohedron prominent in the other types, y, $32\overline{5}1$, + R5. No other scalenohedron is present but both first and second order prisms are found and a series of negative rhombohedrons; of these the only one accurately determined by measurement was e, $01\overline{1}2$, −1/2R. The others form a more or less rounded surface between e and the prism m, but the edges of the scalenohedron truncated by planes of a rhombohedron on several crystals, indicating the form X, $07\overline{7}2$, −7/2R, shown in the drawing, and one measurement from a sharp face gave a value corresponding to L, $08\overline{8}7$, −8/7R which is also indicated in the figure.

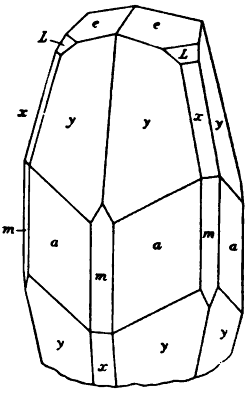

FIG. 3.—Calcite crystal of the square type from the Harris bed at Lime Rock.

m $10\overline{1}0$ ∞ P
a $11\overline{2}0$ ∞ P2
e $01\overline{1}2$ −1/2R
L $08\overline{8}7$ −8/7R
$07\overline{7}2$ −7/2R
y $32\overline{5}1$ +R5

DEXTER QUARRY.

The rock at the Dexter quarry, at Smithfield, is called locally the Dexter rock or the South rock. This outcrop is next in importance, economically, to the bed at Lime Rock, and is still worked in an extensive quarry for lime. It ranges in width from 12 to 15 rods and extends several times this distance on the strike. It is cut off abruptly on the south by the green schists but may extend far north in the depressed area beneath the till.

It is greatly jointed, pure white to gray banded, and carries fewer minerals than the former bed, quartz and calcite crystals and talc pseudomorph after tremolite being the only common ones found.

Octahedrite is reported as occurring in small crystals at "Dexter's lime rock at Smithfield, R. I."[a] I had not been able to verify this citation, nor to find any trace of the mineral at the locality, nor any specimen of the mineral from this place in any collection until recently Professor Palache wrote me that he had found in the Cambridge Museum a very pretty specimen, in a collection from the Dexter quarry made many years ago by Prof. M. E. Wadsworth.

BEDS WEST OF PROVIDENCE AND PAWTUCKET.

Doctor Jackson mentioned several small beds of limestone on the Aza Arnold farm.[b] This is the bed a mile west of Lonsdale, which is 20 to 30 feet wide and 300 feet long, and has now been about all quarried out. Unlike the other beds, this is isolated in the granite, but lies near the border of the green schist. It is bordered on the east side by a bed of tremolite rock several feet thick, and on the west by a similar thick bed of compact talc which is fibrous and pseudomorphic after tremolite. Both these beds have been derived from the limestone, and the transition can be plainly seen. The bed as a whole can be traced southeast with the strike for a mile to near Saylesville by a series of tremolitic serpentine outcrops.

Doctor Jackson mentions[c] also an extensive bed of limestone on the farm of Nathan Brown, 4 miles from Providence, which was worked for lime before the discovery of the Smithfield lime rocks. The bed is about 6 rods wide, and is included between hornblende schist and a compact altered graywacke that is nearly as crystalline as granite. Chlorite slate rocks in beds 10 feet thick lie southwest of the limestone, and include beds of talcose rock or soapstone. Green, acicular, and fasciculated actinolite and crystals of magnetic iron ore of an octahedral form are found here in chlorite and green talc. Granular and compact limestone also occurs on the Olney farm, in hornblende rock associated with beds of chlorite slate, soapstone, and serpentine. Coarsely granular layers of a bright-pink color occur west of the road on the west slope of Neutaconkanut Hill. They alternate with green chloritic limestone. The rock may contain some rhodochrosite. Associated with it are heavy beds made up of brown garnet and green epidote.

CRANSTON BED.

An ore bed is marked on Doctor Jackson's map at a place in Cranston, and this was the site of an iron mine. Professor Woodworth says of this bed: "The iron of the old mine in Cranston in the 'dug-

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[a] Kunz, G. F., Mineral Resources U. S., 1883-84, p. 772. [b] Idem, p. 57. [c] Idem, pp. 80, 81.

way' is probably a ferruginous replacement of the limestone." In the bed of a small brook above this mine there is a vertical bed of limestone 10 feet thick.

ATTLEBORO BED.

In the Massachusetts State collection, under VII, Devonian or Old Red Sandstone rocks, there is a specimen marked "88 Petalite in limestone, Attleborough." This is a white chalcedony in a white crystallized limestone that effervesces with cold acid. This is wholly unlike the compact limestone interstratified with red shale from the ordinary Cambrian at Attleboro, and is exactly like the crystalline limestone of the green schist. It may be that it is a contact product of the intrusives of the region around Attleboro, which lies outside the area of our investigation. This may be taken to slightly increase the probability of the derivation of the green schists from strata similar to the Cambrian rocks at Attleboro, as maintained on page 33.

BEDS IN WOONSOCKET.

The green schist with limestone extends in scattered fragments out over the granite to the north and west. Thick beds of coarse pink marble occur in pyritous quartzose mica schist in Woonsocket.

A 3-inch layer of very coarse calcite (each grain 1½ inches square) occurs in a coarse biotite schist carrying coarse prisms of sillimanite in North Smithfield. These are just beyond the limits of the area mapped in Pl. I.

CONTACT ROCKS ON THE MILFORD GRANITE AND OTHER IGNEOUS ROCKS.

GENERAL FEATURES OF THE METAMORPHISM.

The normal members of the Cambrian formation are a fine-grained generally aphanitic chlorite slate, a fine-grained hornblende schist, a white crystalline limestone, and a slightly muscovitic saccharoidal quartzite. These represent the normal minimum of metamorphism which may be ascribed to the mashing to which the pre-Cambrian and Cambrian rocks were subjected, probably in Ordovician time and before the advent of the Milford granite.

In a broad band adjacent to the Milford granite these normal rocks are at some points greatly altered; the slates have become coarse chloritic or biotitic amphibolites, the limestones have changed to tremolite rock which may show transitions to steatite or impure steatite-serpentine masses, and the quartzites have become dark biotite schists. We have associated with these contact rocks some similar beds from the interior of the series for reasons given below.

The whole Cumberland region and the smaller area to the south are in effect large inclusions in the great batholith of Milford granite.

This is the justification of the term "batholithic structure" applied by Woodworth. The large Lonsdale limestone bed described above is inclosed wholly in this granite. The great beds of tremolite which have been formed from this limestone at the contact (since the limestone is wholly inclosed in the granite) can best be explained as formed by the union of silica derived from the granite with the bases of the limestone.

Southeastward for a mile along the strike, and at the same time along the border, there extends a thick bed of massive impure serpentine, or steatite-serpentine mixture, whose massiveness suggests an igneous origin, but whose fibrous texture indicates its derivation, through a tremolitic stage, from the limestone bed, as does its position in the strike of the limestone. The same kind of rock occurs at several other places on the border, as indicated on the map. These occurrences we ascribe to the contact influence of the Milford granite. Therefore, when we find the same impure serpentine and steatite rock associated at many places with the coarse garnet rock and forming a continuation of the great limestone beds in the midst of the green schists, we may fairly conclude that the granite beneath has produced the change, as at the border. Indeed, a small amount of granite appears at places where the serpentinous change is best developed, as at a point just north of the Lime Rock quarry. Where the tremolite border is lacking on the limestone beds, as it generally is in the interior of the limestone region, the granite was too distant to effect the change.

Again at some places the least altered beds of hornblende schist and chlorite schist contain pebbles and grade into quartzites and are interstratified with limestones; at other places the most highly crystalline beds, in which the coarse hornblende schists are porphyritic with large hornblende crystals and contain plagioclase, are also interstratified with limestone beds or their derivatives—tremolitic and garnet-epidote rocks and ore beds—and every gradation can be observed between the two kinds of rock. Thus some of the beds, such as the diorites described below among the igneous rocks, still show trace of igneous origin and are undoubtedly igneous, while other tremolitic and hornblendic beds are of different type and under the microscope and in the field give evidence of sedimentary origin. In this section we have considered only those contact effects which are exomorphic to the granite. A broad band of the latter is generally much darker than usual, a probable result of differentiation, though this is not so marked as in Massachusetts, where a broad hornblendic band is usually present.

CONTACT ROCKS DERIVED FROM THE LIMESTONE.

Tremolite rock and serpentine.—An interesting outcrop of a partly serpentinized tremolite rock occurs in Lime Rock, near the point where the road turns off to the quarry. It is a massive greenish-gray rock, having the appearance of serpentine, with abundant black porphyritic crystals that show the cleavage of hornblende.

The black-looking crystals are colorless hornblende, their black appearance being due to an abundance of magnetite arranged along the cleavage planes. The ground between these black crystals is made up of a matted network of tremolite needles. In this rock the grains of iron oxide are in some places so arranged that they mark out a former hornblende cleavage over large areas, showing that in these areas there were formerly large tremolite crystals that have by a kind of paramorphism been changed into the tremolite needles. Large patches are changed to a green serpentine. The great amount of the iron in the limestone has doubtless been brought in from the adjacent basic tuffs, and the ore beds mentioned above represent a more complete replacement of the limestone.

Several slides cut from the large dikelike mass 50 rods long by 20 rods wide on the top of the serpentine hill, just north of the Lime Rock quarry, are of the same type as the rock east of the Lime Rock road, and the two outcrops have been connected on the map. The rock is massive and of dark-gray color, the black hornblende crystals showing more or less distinctly. The serpentinous change in this rock is farther advanced than in the rock described above, and at many places only the dense masses of magnetite grains, with angular boundaries, indicate the former presence of the large crystals of hornblende, since this and the finer fibrous tremolite have changed to a mat of serpentine blades.

Tremolitic serpentine.—A rock from the granite contact, three-fourths of a mile southwest of the Lime Rock quarry, in Lincoln, is a dark-gray, harsh-feeling serpentine, full of large tremolite blades and rhombs of dolomite.

The slide (356) shows a black-dusted homogeneous serpentine made up of slightly polarizing flakes and showing traces of the rectangular cleavage of a former mineral, perhaps a pyroxene. Each of the untwinned rhombs of dolomite is surrounded by a band of dolomite differently orientated.

Steatite.—Just west of Manville, at the fork in the road, is a bed of a soft, dark-gray, coarse-grained steatite full of large rhombohedra of ankerite, many of them one-half inch in diameter, which range in color from wine-yellow to black. Another similar bed occurs a half mile west of Manton. These beds seem also to have been derived from a magnesian limestone, but have passed through an actinolitic stage.

Prof. C. W. Brown called our attention to the Indian "Ollah" quarry at Merino, where half-finished pots still remain attached to the ledge.

Garnet rock.—In the hill north of the Lime Rock limestone quarry, at the serpentine locality in the green schist, there is a thick short band 4 inches wide of brown-red garnet, and on each side of this there is a band 2 inches wide of a fine, granular, pistachio-green mass mixed with granular limestone. The rock contains much fine crystalline magnetite. The garnet is without strain or inclusions. The green mixture is fine, fibrous actinolite filled with fine granular epidote. Here and there are white, fine, granular veins of quartz. The rock passes into an epidote-garnet quartzite. A garnetiferous quartzite appears also as a border bed to the limestone at the Dexter quarry, and in considerable quantity in connection with several other limestone beds.

CONTACT ROCKS DERIVED FROM THE GREEN SCHISTS.

On Neutaconkanut Hill, west of Providence, and at points farther south, we were compelled to map separately a broad contact border because on the one side small offshoots of the granite intricately penetrate the schists and on the other the schists become coarsely crystalline. Generally the line of contact of the granite and the schists is remarkably straight, no lobes of the granite penetrating the schists. Here, however, the granite is intimately mixed with the schists in thin layers, which are at many places intruded between layers of the schist, and although the rocks here are all much more coarsely crystalline than usual the schist, limestone, and quartzite can still be distinguished from one another and from the granite.

Farther north, in Massachusetts, the Milford granite is at many places bordered by a black hornblende band, much injected by small granite veins, and part of this band may be of the same origin as that just described, but the calcareous and ferruginous green schists are so well fitted to change to similar hornblende schists that it is not easy to separate the two.

The common rock at the border on Neutaconkanut Hill is dark porphyritic, being closely dotted with perfect, stout, black hornblende crystals from one-eighth to one-fourth inch long, in a light groundmass made up of fine white grains of quartz and feldspar. The microscope shows it to be a biotite-actinolite-epidote schist. It is without calcite or magnetite, but is very cavernous at the surface, from the removal of some constituent. The large, perfectly bounded hornblende crystals are partly or wholly replaced by aggregates of biotite scales, which, where the replacement is partial, are in some cases grouped in the center of the crystal and in others are arranged in an annular band at or near its border.

The contact rocks are well shown along the road in North Providence, 2 miles south of Olney Pond. The noncalcareous chlorite-sericite schist can be traced into a greenish-gray massive rock containing a green mica in a fine-granular quartz-feldspar ground. The intervening calciferous green schist passes into coarse-grained dark green, pyroxenic amphibolite, or a light-colored gneissoid rock mottled by black, square, hornblende crystals or similar square biotite aggregates, as at Neutaconkanut Hill. We may assume that the first influence of the granite here was thermal, producing the coarser crystallization of the hornblende; the second chemical, consisting of a transfer of alkaline solutions from the granite to the schist, whereby the enlarged hornblendes have been in whole or part changed into groups of biotite scales.

A very peculiar rock occurs by the north-south road at the northwest foot of Neutaconkanut Hill. (See Pl. II.) It is the common greenish-black contact form of the calcareous green schist, massive, aphanitic, and homogeneous in appearance when freshly broken, but developing on weathering the two structures shown in the figure—distant, straight, parallel ridges, which seem to represent a concealed foliation, and stout, prismatic projections, which generally comprise regular crystals that have more or less rounded edges and give in cross section the angles of hornblende. These crystals represent a mineral that has grown in the green schist during its first transformation, with only a partial expulsion of the original material of the soft schist—that is, they have grown in the schist somewhat as chiastolite grows in clay slates.

An examination of these crystals in thin section (466) bears out this conclusion. The crystal cross sections are markedly different from the surrounding ground, but their composition is so variable that they differ from one another as one kind of rock differs from another kind. The magnetite octahedra, single and grouped, are equally abundant in the crystal sections and in the ground outside, showing that the magnetite was crystalized before them both. The ground is a mica schist in which half the surface is of olive biotite scales in a colorless ground. The crystals are formed of a green substance, not resolvable by the lens, which is shot through by colorless rods in a sort of micrographic arrangement. There are also some biotite scales somewhat larger than in the ground. With the microscope the groundmass is seen to be made up of the small angular and rounded quartz grains of a very fine-grained sandstone (exactly like the calcareous sandstone described on p. 14) in which the biotite blades and magnetite are disseminated.

The large hornblende crystals preserve one original structure. This is a poikilitic intergrowth of plagioclase, still wholly fresh, which is regularly spread throughout the crystal nearly to its border, or appears in broad patches. It is in long notched rods and plates more or less

PORPHYRITIC GREEN SCHIST.

The ground is a dark mica schist. The distinctly crystalline projections are made up of matted actinolite, pseudomorphous after pyroxene or hornblende. (See page 32.)

rounded, with a parallel arrangement in places, as if controlled by the host. The plates are only rarely twinned and then extinguish at 23°.

The normal growth of the large hornblendes continued slightly after the intergrowth had ceased and then sometimes a few blades shot out from the ends of the large crystals, becoming themselves rather large, branching, and fasciculate, as in garben-schiefer. Groups of the same fasciculate actinolite occur independently. The whole of each large hornblende crystal was then changed into an exceedingly fine-grained felt of actinolite needles of several sizes, mostly so fine and overlapping that they present with low power an almost amorphous mass in which the larger blades shine out.

The rock was a very fine-grained calcareous and ferruginous sandstone, in which first a part of the iron crystallized in the black octahedra and a foliation was produced during the folding of the rock. Then followed the crystallization of the stout hornblende crystals with at first an intergrowth of a lime feldspar, producing a structure not uncommon in limestone contacts. We may infer that these crystals were not formed during the folding of the rock, since they cut across and disturb the remains of the foliation. As this required only the constituents of the original rock, we may assume that the heat of the adjacent granite produced the change. Then followed the development of the abundant biotite in the ground outside the crystals, and this also may be brought into connection with the intrusion of the great granite masses, which involved the sending out into the green schist of alkaline solutions that contributed the potash that joined with the magnesium and iron to make the abundant biotite of the ground. This regularly disseminated biotite is absent from the hornblende crystals, because they were formed at an earlier period. The heat of this intrusion may have caused the paramorphism of the bisilicate to a uralitic pseudomorph.

CONTACT EFFECT OF THE MILFORD GRANITE ON INCLOSED CAMBRIAN SCHISTS AT THE SAYLESVILLE GRANITE QUARRY.

The phenomena described below were at first believed to indicate the post-Carboniferous age of the Milford granite and to suggest that the sericite schists of the Carboniferous border may be due to contact metamorphism caused by that granite. A special study, therefore, was made of the Saylesville quarries northwest of Pawtucket, in Lincoln, because of the interesting inclusions of schist in the granite at that place.

The inclosing rock is a gray biotite granite, coarse, often subporphyritic, containing in some places blue quartz, and much jointed. At the time the quarry was visited, in 1900, large masses of pale greenish schist rose from the floor of the quarry with a width of 3 to

4 rods, a strike N. 35° W., and dip of 50° NE. Pieces taken from the centers of the masses are a soft, greasy sericite slate of leek-green color, closely like the original sericite schist of the Taunus. It is found that a portion of the Albion schist farther west is closely like the least altered portion of the included masses.

At the border the rock is granitoid and the quartz and feldspar of the granite are diffused through the dark material of the schist. For several feet beyond the border of the granite and schist the granite has lost its normal subporphyritic texture and seems to have been shattered by the influence of the moisture of the inclusion and recemented. Outside this belt on every side the granite shows its normal and original texture, with coarse fresh feldspar and distinct biotite films.

A slide (371) was cut from this granite at its contact with the large inclosure. The rock is thoroughly shattered, narrow granulated bands running through several grains and recementing them. The quartz is generally a mosaic, but at some places the rock contains blue quartz in perfect crystals, which are penetrated by lobes of the groundmass. It contains also squarish broken feldspars, some of which are orthoclase, judging from their refraction, but the commonest feldspar is albite. Pale red garnets surrounded by a kelyphitic rim of pale amber pyroxene appear, and also a colorless, limpid, isotropic mineral with purple border, doubtless fluorite. The slide shows also apatite and brilliant zircons.

Under the microscope the inclosed slate in its central portion is seen to be composed of matted parallel filaments of sericite with wavy boundaries dusted full of the coaly and clayey material of the unaltered slate and differing entirely from the nearest green schist, which is made up of sharply outlined crystals of actinolite, biotite, and epidote. The transition of this slate to microflaserig mica schist is clearly traceable. Near the center of the slate are a few lenticular groups of interlocked and greatly strained quartz grains, and these increase in number and size outward, away from the central portion, until a clear flaserig texture is produced and the micaceous films undulate between the augen of strained and interlocking quartz grains as if they had been spread apart by the growing quartz. These grains are often full of rutile needles, like true granite quartz. There is thus far no new mineral except the blue quartz added to the original schist, which consists of white and brown micas, chlorite, and a granular mineral which seems to be epidote; but in one section taken only a foot from the border feldspar, both orthoclase and plagioclase, is introduced in rather large crystals, forming a perfect paragneiss. In specimens taken just adjacent to the granite the grains of quartz and feldspar are larger, more abundant, and more irregular in size and shape, and are included in a small amount of the dark schistose material, which may explain the granite-quartz grains mentioned above.

The sharp border of the great blocks of schist against the granite and the uncrushed condition of the granite away from the border show that the two rocks have not been subjected to a common mashing since the granite cooled. The complete mashing of the schists elsewhere in the region has produced no blue quartz. The blue quartz is the characteristic of the inclosing granite. The granite has thus penetrated the schist for some distance; the blue quartz has been carried in solution still farther in, but is lacking in the central part. This occurrence is analogous to that of a granite stock which sends out into a country rock pegmatitic apophyses that grade outward into quartz veins.

CONTACT ROCK FROM THE GRAFTON QUARTZITE.

An interesting contact rock on the Milford granite occurs in the quartzite west of Manton. It is a black, very fine-grained mica schist that shows in the slide (437) colorless spots in a fine-grained biotite schist, thus having a porphyritic aspect. With polarized light these spots prove to be a colorless uniaxial mica, within which all the grains of the original sand still retain their places. Here also potash was introduced in large quantities, forming biotite.

AGE RELATIONS.

Professor Woodworth proposed the name "Blackstone series" for the complex of quartzites and green schists along the bed of Blackstone River.[a] The limestone and the hornblende rock of this series were assigned to the Primary by Dr. C. T. Jackson, in 1840, in his report upon the geology of Rhode Island. Prof. Ebenezer Emmons referred them, in 1846, to the Taconic[b]—that is to the age of the Stockbridge limestone in the Cambrian or at the base of the Silurian—an assignment which seems probable.

Professor Shaler, in his paper upon the Cambrian of Attleboro,[c] devotes three pages to a discussion of the character and age of the "Blackstone series." He regards it as of sedimentary origin, considers it pre-Cambrian, possibly Huronian, and estimates its probable thickness at more than 5,000 feet. He states that pebbles of the "Blackstone series" are found in the Cambrian, he having then assigned all the red beds in Attleboro to the Cambrian. Later, Foerste, Woodworth, and Shaler[d] give a much less area to the Cambrian, and do not cite pebbles of the "Blackstone" in the true Cambrian. The strike of the "Blackstone series" is northwest-southeast; that of the Cambrian at Attleboro northeast-southwest. Professor Woodworth

[a] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 106.

[b] Agriculture of New York, vol. 1, 1846, pp. 90–93; also American Geology, vol. 1, 1855, p. 22.

[c] Shaler, N. S., On the geology of the Cambrian district of Bristol County, Mass.: Bull. Mus. Comp. Zool., vol. 16, No. 2, 1888, pp. 15–18.

[d] Mon. U. S. Geol. Survey, vol. 33, 1899.

bases the idea of a difference in age between this series and the Cambrian rocks on the fact that the Blackstone beds are greatly metamorphosed, the fossiliferous Cambrian very little, and refers the series to the Algonkian period. He says:[a]

The determination of the pre-Cambrian age of the group of limestones, schists, slates, and quartzites in the Blackstone River area rests upon the relation which it bears to the Lower Cambrian strata in North Attleboro. The Olenellus fauna occurs in little-altered, red, calcareous shales and slates at this latter place in close proximity to granite (hornblendic granitite). Four miles west of this inlier of the Carboniferous area occur the sediments involved in the complex already described. These strata are highly altered sediments, now hornblendic and chloritic schists, mainly of a green color, altered sandstone or quartzites, and crystalline limestones. The presumption that these rocks are pre-Cambrian rests, at present, therefore, on the difference in metamorphism between them and the Lower Cambrian rocks in the same field. The criterion appealed to in this case is embodied in the statement that where two sets of rock coexist in the same dynamic field, that group which has undergone one dynamic movement more than the other is the older. If this view is maintained, this series of rocks falls into the Algonkian. Evidence of unconformity with the Lower Cambrian is necessary to make this conclusion positive. The relation of the granitic intrusives to the pre-Cambrian on the one hand and to the Cambrian on the other is simply to show that the granitite is younger than the former, and that the sedimentary rocks are of different ages.

The reasons which have led us to believe that the "Blackstone series" is Cambrian and that it is the equivalent of the "Attleboro series" are as follows: The highly ferruginous and highly calcareous green schists must have been derived from rocks exactly like the red calcareous shales of the "Attleboro series" and the quartzites from rocks closely like the sandstones of the Braintree Cambrian. Evidence that there is a considerable bed of highly crystalline limestone in the Attleboro area is given above (p. 26).

When these rocks are traced farther northwest it is found that they wrap round a series of coarse, porphyritic, granitoid gneisses like the pre-Cambrian of the Berkshire Hills, and they are themselves indistinguishable from the Cambrian quartzites of Berkshire. Although the two are only 2 or 3 miles apart, the Attleboro rocks lie along a zone of least metamorphism, while the Blackstone rocks lie along a zone of maximum metamorphism. To make this point clear there is reproduced in fig. 4 a map drawn by Professor Woodworth, which shows a zone of maximum disturbance of the Carboniferous rocks extending along the west side of the basin and a zone of lesser change extending along to the east of the former. To Professor Woodworth's map have been added the areas of the "Blackstone series," marked *d*, which it will be seen lie in the continuation of this zone of maximum metamorphism, and the area of the Attleboro fossiliferous Cambrian, marked *e*, which lies in the zone of least change. The Carboniferous rocks in Attleboro contain annelid markings, impressions of

[a] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 105.

raindrops, etc., and are as little altered as the Cambrian there, while farther west, adjacent to the "Blackstone series," Carboniferous conglomerates are metamorphosed into the semblance of granites and into coarse, crumpled mica schist, while the shales are changed into very coarse ottrelite garnet schists, fully as much metamorphosed as the green schists. Professor Woodworth emphasizes this contrast and the suddenness of the transition. He says:[a]

The geologist who should pass from the nearly vertical metamorphic strata of the East Side in the city of Providence, R. I., to the slightly folded and unaltered shale beds of East Providence would, from a comparison of the rocks alone, be led to infer that there was in this field a set of very ancient tilted rocks flanked on the east by strata of much less antiquity. So short is the space between the two rock phases at this point, being the width of the Seekonk River only, that one is led to believe that an intermediate zone of considerable width has been concealed by a fault.

FIG. 4.—Map showing distribution of metamorphosed Carboniferous rocks. *a*, Narragansett Bay area of maximum metamorphism; *b*, Winneconnet area; *c*, Morrill's area, in Norfolk County basin; *d*, Cambrian; *e*, Attleboro fossiliferous Cambrian area.

We may be sure that the Cambrian of the Attleboro area extended some miles farther west of its present limits at the time of its deposition. Indeed, a small area of Cambrian rocks is shown by Professor Woodworth[b], with associated hornblende granite, only a mile from the green schist, on the north border of the Diamond Hill felsite. The geologic history of the region will present to our minds a much simpler picture if we assume that these rocks are represented in an altered state by the wholly similar "Blackstone series" and, farther west and northwest, by the Grafton quartzite and the Marlboro amphibolite, which wrap round the older Northbridge granitoid gneiss. The alternative hypothesis would involve an additional incursion of the sea into the region in pre-Cambrian time, to account for the deposition of the green-schist series. The same hornblendic granite appears in the Cambrian near the fossil beds and in the "Blackstone series" near Albion.

[a] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 119. [b] Idem, Pl. XVII.

Green schist underlies Carboniferous rocks at the south end of Conanicut Island[a], and there is a large area in Little Compton, made up mostly of quartzite with some green schist, that is referred by Foerste to the Cambrian, with some reserve. Similar rocks occur about Newport Neck and Newport Harbor. To justify the probable correlation of these rocks at the mouth of Narragansett Bay with the Cambrian beds at North Attleboro, Mr. Foerste cites the very fact noted above, viz, the presence of layers of limestone in the Newport beds in considerable abundance, as in the Attleboro beds, and their absence from the Carboniferous.[b]

In relation to the quartzites and green schists of the "Blackstone series" from Natick to Manville, he says:[c]

> The question as to the geological position of these quartzites is very important, but is at present without a solution. On lithological grounds alone they might be considered of Cambrian age, but there is little real basis for such a determination. Perhaps the best reason so far known for considering these quartzites as of Cambrian age is the abundant occurrence of Cambrian quartzite pebbles in the Carboniferous conglomerates of the Narragansett basin.

But while the quartzite pebbles occur in all horizons in the Carboniferous those containing Cambrian fossils appear only in the upper beds, and these quartzites differ from any known outcrop of quartzite surrounding the basin. Moreover, while the fossiliferous quartzite pebbles are quite abundant in the Carboniferous, the quartzite beds around the basin are nonfossiliferous.

The "amphibolite aggregate" of Hitchcock (Mass. Col., VII, 102) from Middletown, near Newport, is made up of dark biotite changing to chlorite shot through with hornblende and very like the rock along the Blackstone, and the zoisite, which is cited as occurring with it (VII, 124), is in a sheet an inch thick, having a columnar structure. The rocks of Little Compton and Conanicut also bear close resemblance to those of the "Blackstone series."

The limestone of the Attleboro locality, of the Newport locality, and of the "Blackstone series" are alike in amount and distribution and in thickness of beds. A comparison of the analyses of the Newport and "Blackstone" limestones on page 17 will show that they are both prevailingly dolomitic.

In the harbor of Newport there are two islands of yellow, compact limestone, which are highly magnesian and manganesian.[d] The larger of these islands is 90 feet wide and 210 feet long; the smaller is half as large. At Fort Adams, in Newport Harbor, there are limestone beds 45 and 15 feet wide.[e] It is true that these limestones are less crystalline than those of the "Blackstone series," as the flinty slates associated with them around Newport are less metamorphosed than

[a] Foerste, A. F., Mon. U. S. Geol. Survey, vol. 33, 1899, p. 234.
[b] Foerste, A. F., idem, pp. 381–383.
[c] Idem, pp. 383–385.
[d] Jackson, idem, p. 84.
[e] Idem, pp. 91, 92.

the schists associated with the Blackstone rocks. In degree of change they are in fact intermediate between the two extremes, and they lie geographically along the band of transition between these two extremes. The crystalline limestone from Attleboro, cited on page 26, shows that the rock there may be in some places as crystalline as that from the Blackstone region.

A comparison of the altered limestones of the "Blackstone series" with the Cambro-Silurian limestone of the Housatonic Valley and the pre-Cambrian limestone of the Berkshire Hills is interesting in this connection.

The abundant tremolite, actinolite, canaanite, garnet, epidote, and iron ores of the "Blackstone" are closely like the derivative minerals of the western valley limestone (Cambrian), while most of the characteristic minerals of the older limestone are wanting, or rare, viz, phlogopite, chondrodite, scapolite, spinel, titanite, dark pyroxene, pyrrhotite.

CARBONIFEROUS ROCKS.

SCOPE OF THE DISCUSSION.

The pre-Carboniferous rocks in the Providence and Narragansett Bay quadrangles will be next considered, the discussion covering the ground not occupied by Messrs. Shaler, Woodworth, and Foerste in their monograph on the geology of the Narragansett basin.[a] It was not their purpose to report upon the isolated patches of Carboniferous conglomerate that rest upon the crystalline rocks in the area that lies west of the line which they had set as the western boundary of the basin, nor did they occupy themselves especially with some of the problems connected with the metamorphic changes of the Carboniferous rocks in immediate contact with the granite along the western border of the basin. Some of these problems are therefore here discussed, but no attempt is made to present a general description of the Carboniferous rocks.

CARBONIFEROUS BOUNDARY.

The high bluffs of crystalline rock extending northward from the southern edge of the area mapped are taken as the approximate boundary of the Carboniferous, although in the low ground at their base the conglomerates are not exposed for 6 miles to the east. From a point west of Wickford Junction, a half mile west of the edge of the Narragansett Bay quadrangle, the boundary of the conglomerate could be closely traced northward by bowlders. The character of the boundary along this line could not be determined.

The easternmost ledges in bluffs east of Davisville show traces of much-altered conglomerate. From this point to Natick the bluffs

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[a] Mon. U. S. Geol. Survey, vol. 33, 1899.

everywhere show ledges of the older rocks, and the boundary of the Carboniferous is concealed beneath the Quaternary deposits.

From Natick northward for 2½ miles into Cranston the boundary is well exposed in the bluffs. Beyond this point it is partially exposed on to Knightsville. It is a normal boundary on the different Cambrian formations and on the Milford granite. In the area just north of this the conglomerates are exposed at only a few places, and are not represented in that section on Professor Woodworth's map. We found traces of the basal beds as far north as Geneva, west of Providence. North of this point argillites adjoin the crystallines, except for a short distance southeast of Hunting Hill, and we have followed Professor Woodworth in assuming a fault along this portion of the boundary.

Just at the northwest corner of the area mapped begins another large area of the Carboniferous conglomerate in Woonsocket, the white quartzite pebbles in which are in some places mashed to rods and plates 12 to 14 inches long.

CARBONIFEROUS CONGLOMERATE.

CHARACTER AND DISTRIBUTION.

In the bare bluff above the church in the village of Natick the Carboniferous conglomerate rests in normal contact on massive jointed Cambrian quartzite. It is a very coarse conglomerate; one block is 3 feet in diameter, and many of the blocks are angular. A little farther north a fine greenish quartz groundmass envelops the large cobbles. This purely quartzose facies is confined to the basal portion of the conglomerate and to places where it is in immediate contact with the Cambrian quartzite.

Eastward across Natick, away from the contact, the pebbles become smaller. Many of them appear to be of a finer and whiter quartzite, but prove under the microscope to be a microgranite exactly like that which forms the border of the conglomerate for a long way south in East Greenwich. Pebbles of granite also occur, and these also, when studied in thin section, prove to be of the type of the East Greenwich granite found farther south, and quite unlike the Milford granite, found farther east and north.

A fine-grained interstitial material developed between the pebbles is metamorphosed into a shining white finely crumpled muscovite or sericite schist, in places full of small magnetite octahedra and spangled with biotite. Some specimens contain small garnets and chloritoid.

The friable microgranite pebbles crush easily, and, mingled probably with fine material of the same character, form this sericite schist. Many quartzite and granite pebbles remain intact and the microgranite pebbles wrap round them. Some of the pebbles are penetrated by

large secondary magnetite octahedra for an inch in from the surface. These octahedra also fill the paste and were doubtless carried into the pebbles under heavy pressure by the same solutions that brought the biotite, and both seem to have come from the micrognanite, the only magnetite-bearing rock that is common in the conglomerate.

Between the church and the schoolhouse in Natick there is a completely crushed zone of sericite schist. Farther on, through and east of the village, are abundant outcrops of the conglomerate with sericite-schist paste as described above. In Natick the transition from the basal, locally derived, quartz conglomerate to the micrognanitic conglomerate derived from the East Greenwich rocks to the south is so sudden that we have suggested that the eruptive material was furnished by an explosive rupturing of the dome of the East Greenwich mass rather than by erosion. (See p. 69.)

The interesting relations of the conglomerate to the adjacent rocks in Natick and at a point a mile north of that place are beautifully shown in abundant outcrops.

One who follows the boundary three-fourths of a mile northward from Natick Church to the point where it crosses the east-west road will come to a point where the conglomerate rests on the Milford granite. This boundary can also be followed by abundant outcrops northeastward over a wooded hill to a place where it crosses the road and the Cranston line at the same time. The conglomerate contains abundant large cobbles, embedded in a paste of sericite schist. The majority of these are quartzite which has drifted northward from the Natick ledges. There are also many pebbles of microgranite and a few of granite, which might lead one to assume that they were derived from the adjacent Milford granite, and to infer the granite to be the older. But the quartzite pebbles are angular and larger, the microgranite and the granite pebbles are rounded and smaller, which would harmonize with the idea that they were far traveled and had been derived from the East Greenwich series which formed the shore to the southeast beyond the quartzite. The Milford granite is a coarse biotite gray-quartz microperthite rock. The granite in the pebbles is a blue-quartz plagioclase granite containing garnets and showing a marked micrographic structure, characters that are found in the East Greenwich pre-Carboniferous granite, but not in the Milford granite. The material is thus all far traveled.

Seven rods east of the bare rocky southern apex of the hill along which the boundary runs is a contact of the Milford granite and the conglomerate which might be interpreted as an intrusive contact, since it runs east-west (the prevailing direction of the boundary being north-south) and cuts across the laminæ of the sericite schist. The alteration of the rock here is probably due to crushing. The extreme

metamorphism of the conglomerate, combined with the small amount of mashing and jointing, is very characteristic.

One-half mile east of Natick, near the base of the conglomerate, all the pebbles retain their shape and the paste is a coarse sericite schist full of biotite, garnet, and chloritoid.

On the Cranston line black amphibolite and green schist pebbles appear in the conglomerate. Here the adjacent rock is the green schist, but the far-transported material still predominates. If we follow the boundary 3 miles farther north, to the great hill a mile and a half southwest of Knightsville, we come on an area where the granite and the conglomerate are so mashed together that the whole east slope of the hill may be looked upon as the contact surface between the two. At the south end and just west of the road, in front of a new country house, the large ledge is on one side completely granitoid in aspect; on the other large rounded cobbles 6 to 8 inches long can be clearly distinguished.

In the northern part of this area, one-half mile west of Wayland station, the conglomerate becomes a shining muscovite schist with finely corrugated foliation surfaces, while the pebbles are in part present in broad, flat disks, and here and there a perfect cobble of granite 4 or 5 inches across remains quite intact.

The same blending continues farther westward between the Milford granite and the sericite schist, and distinct traces of pebbles rarely appear in the latter. A slide of the Milford granite from one side of a ledge near the summit showed uncrushed microcline with biotite in small distant bands. This granite appears in great force farther west. Another slide from a spot a few feet farther along the same ledge was a sericite schist with distant distinct biotites and garnets and strained blue quartz (all characteristics of the altered conglomerate and wanting in the adjacent granite), but with a single filament of microcline granite showing the intimacy of the blending.

OUTLIERS OF CARBONIFEROUS CONGLOMERATE ON THE BRECCIA OF THE EAST GREENWICH GROUP. [a]

One who follows the road along the south slope of Spencer Hill in Warwick westward will keep on the breccia for a considerable distance. Turning then northward along a road he will come, in about 40 rods, to a small schoolhouse. Just north of this school is a very interesting ledge that is broadly exposed on either side of the road. Areally it seems to be a part of the breccia, which is in place on every side, but it is plainly a thin film of the conglomerate, about 3 rods square, resting on the breccia, and as the abundant interstitial material is a fairly pure muscovite schist we are compelled by all our previous experience to assume that it is a Carboniferous conglomerate. It

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[a] See p. 64 for description of the breccia.

contains red garnets, many of which are found in the altered paste of the Carboniferous conglomerate, and a few Cambrian quartzite pebbles (the larger angular and 2 inches across), as well as clastic grains of various feldspars, microcline orthoclase, oligoclase, and a few of blue quartz, of types exactly like those derived from the blue-quartz porphyry and the porphyritic microgranite. It contains also pebbles of the blue-quartz porphyry and of the granite, and one specimen exhibits a small block of the breccia with a half dozen fragments, each an inch long, of the graphic microgranite embedded in a paste of the normal blue-quartz porphyry. Adjacent to this block is a rounded pebble of the Cambrian quartzite, which seems at first sight to be also included in the porphyry, but proves, on careful study, to be adjacent to the latter and not included. Most of these grains and pebbles are almost wholly unchanged, although they have been subjected to influences which in places changed the paste into a clear, coarse mica schist. Here and there a feldspar grain is largely changed to coarse muscovite. The grains are also slightly fissured, and, as will be seen below, have probably been penetrated secondarily by magnetite. Rounded grains of quartzite exactly like those in the Cambrian quartzite are surrounded by attached magnetite grains. This magnetite is thus certainly secondary. Where it is spread regularly through the mica-schist paste it is also almost certainly secondary, and as it penetrates the feldspar grains in whole or in part very generally but not always, and as these feldspars are otherwise exactly like the porphyry feldspars which do not contain much magnetite, it is probably secondary here also.

This conglomerate contains also rather large pebbles of a peculiar rock which is so exceptional in character that it has been described elsewhere (p. 64) under the name microclinite as a distinct variety of the rocks of the East Greenwich group. Part of the microcline phenocrysts in this rock have been penetrated by the magnetite that is regularly distributed through it, and part of them have not. The secondary penetration of the magnetite into the Carboniferous conglomerate at the Cranston locality has already been described, and may be considered a second evidence of the Carboniferous age of the rock here discussed.

This film of arkose conglomerate, which contains all types of rocks of the eruptive series and a few quartzite pebbles, probably passed upward into a true Carboniferous quartz conglomerate. It rests on a brecciated fine-grained, graphic granite that is without porphyry cement. These associated rocks, as will be explained below (see p. 69), possibly had their origin in an explosive eruption of the mass of porphyry and graphic microgranite, which furnished the large amount of unaltered igneous material found here and at localities farther east, across Natick and Cranston.

This determination of the age of the East Greenwich group makes it agree in its time of eruption with the "Wamsutta series" and with the "Quincy series" as fixed by Woodworth. The alternative hypothesis, which is very plausible, would be that the breccia was a rather deep-seated formation—a reibungs breccia—that it was uncovered by erosion, and that the material which it has contributed to the Carboniferous conglomerate was transported a long time after. This would make the intrusion pre-Carboniferous. (See p. 67.)

A similar outcrop of the Carboniferous conglomerate rests on the breccia just west of the spring locality of the breccia.

CARBONIFEROUS SHALES AND SCHISTS.

The prevailing rock among the Carboniferous shales and schists is a dark roofing slate, which has reached but a low degree of metamorphism in the area extending from Providence northward, but in that extending from Providence southward consists of much more metamorphosed beds, mainly highly muscovitic schists, here and there spangled with biotite. The rock is at many places just such a spangled mica schist as occurs in the calciferous mica schist (Goshen schist) in the Devonian rocks of the Berkshire Hills and of Bernardston. It is the same light, shining, crumpled muscovite schist, with small black biotite crystals set at all angles to the bedding. There are many much-strained quartz grains, which seem to be derived from the granite and which contain sheets of fluid pores with moving bubbles and rutile needles. The biotite plates blend with the surrounding rock and are full of dark aureoles.

CHLORITOID (MASONITE) IN THE METAMORPHOSED CARBONIFEROUS CONGLOMERATE AND PHYLLITE.

Chloritoid is very abundant in bowlders, but we found it in place only in the brook cutting on the south line of East Greenwich, where it occurs in a shining mica schist, and at a point 40 rods east of the eastern railroad station in Natick, in a fine-grained Carboniferous conglomerate containing uncrushed pebbles in a paste of sericite schist with garnet and biotite. The plates of chloritoid are only one-eighth inch across.

A specimen of a dark-gray silvery schist from Cranston, very similar to the above, is also full of small, thin, black scales resembling biotite, but the rock is more mashed and the scales are of brittle chloritoid, so opaque that only with difficulty could light be seen through the thinnest plates.

A peculiar variety of this masonite occurs as a bowlder in Warwick, 1 mile south of Cowesett and 5 miles south of Natick. This is a coarse-grained massive rock, made up almost entirely of thick, squarish plates of masonite one-fourth inch across, set close together. It contains

scattered red garnets of about the same size, and passes into a coarse garnet rock. Under the microscope c = yellowish, b = indigo blue, a = greenish yellow. This bowlder and the very similar ones found in Natick, which contain larger crystals of masonite, certainly come from the Carboniferous contact area north or northwest of Natick. Some of the great plates of masonite are 1 inch thick and 2 inches across.

The mother rock is the same finely corrugated silvery and finely arenaceous muscovite schist that forms the matrix of the Carboniferous conglomerate, and is doubtless of Carboniferous age. The typical masonite is associated with large garnets, and many of the small black plates that are scattered in the matrix are biotite like that of the spangled biotite phyllite described above.

Doctor Jackson makes the following report concerning the masonite at this locality:[a]

Nearly opposite the brick cotton factory in Natick, upon the roadside, there are three large blocks of a peculiar rock composed of a new mineral associated with mica and garnets. These blocks of stone are erratic and now rest on a totally different rock formation.

I have been informed by Professor Hitchcock that the same kind of rock is met in the town of Ward, in Worcester County, Mass. It is certain that no rock of the kind exists in place in Rhode Island, and it may appear surprising that these blocks should have been removed so far from their native locality. I measured one of them and found it to be 15 feet long, 10 feet wide, and 4 feet thick. * * *

My attention was first called to these rocks by Mr. Owen Mason, in Providence, and I examined them for the purpose of ascertaining the nature of a singular mineral of which they are chiefly composed. This mineral I have analyzed and find it to constitute an entirely new species, to which I propose giving the name masonite, in honor of one to whom the geology and mineralogy of the State is so much indebted. Masonite consists of the following ingredients:

				Ratio.
Water	4.000	containing oxygen	3.555	
Silicic acid	33.200	containing oxygen	17.247	=3
Alumina	29.000	containing oxygen	13.543	=2
Magnesia	0.240	containing oxygen	0.092	
Protoxide of iron	25.934	containing oxygen	5.904	=1
Oxide of manganese	6.000	containing oxygen	1.814	
	98.374			

Its mineralogical formula is $\begin{matrix} Al_2 \\ Fe: \\ Mn \end{matrix}$ $Si_3 + A_2$.

It is a silicate of alumina and protoxide of iron plus silicate of manganese, plus water. Its specific gravity is 3.450. It occurs in tabular crystals which cleave very easily with brilliant planes perpendicular to their axes and with great difficulty in other directions. Its primary appears to be a right rhombic prism. It scratches glass and yields to the knife with difficulty. It is with difficulty fusible to a dark-green enamel.

[a] Idem, p. 87.

This analysis was made at a time when "silicic acid" (that is, silica) was supposed to be a trioxid (SiO_3) instead of a dioxid (SiO_2). The mineralogic formula deduced from the analysis given above is therefore subject to correction.

IGNEOUS ROCKS.

IGNEOUS ROCKS OF CAMBRIAN AGE.

DIORITE.

The diorite of the pebbles in the conglomerate green schist on the hill a hundred rods north of the middle Lime Rock quarry varies in texture from medium to fine grain and shows in one type, on a continuous dull-white ground, black hornblende grains and lobate forms in somewhat regular arrangement. The hornblende increases in amount until the rôles of the two minerals are reversed and the white lobate forms stand out on a black ground. The pebbles vary greatly in coarseness. The adjacent diorite ledge, which borders the great dikelike bed of tremolitic serpentine, comprises all these types of diorite, and in addition other varieties. A diminution of the amount of feldspar produces a black, normal, fine-grained, wholly massive diorite, in which the lens still detects traces of the white constituent, and finally, where it is in contact with the serpentine, a very harsh-fracturing, black, almost aphanitic rock. In another portion of the mass is a coarse black hornblendite, massive and fresh-looking, with the stout phenocrysts often automorphic and a half inch long. Several slides (416, 417, 420, and 422) showed with a lens a gabbroid texture and little or no trace of crushing.

The microscope showed that a common feature of this rock was the abundant occurrence of grains of black ore surrounded by large borders of leucoxene, or even broad, cleaved crystals of titanite, exhibiting no trace of crushing. The white fields have the shape of stout feldspar blades and show in places traces of triclinic striation, but are thoroughly saussuritized and filled with actinolite needles. The dark fields are partly large squarish hornblendes, partly groups of smaller hornblendes. The hornblende shows moderate pleochroism in yellow, green, and bluish green, which may be secondary, but gives no trace of any earlier mineral. One doubtful remnant of pyroxene was noted.

Pebbles of the diorite show a texture that is very similar to that of fragments taken fresh from the ledge, so that the ledge has evidently suffered no considerable metamorphic change since the fragments were broken off in Cambrian time; in other words, it was then, as now, a hornblende-plagioclase rock—a diorite.

Another 20-foot dike which seems to be of the same type occurs in the quartzite one-fourth mile northwest of Albion, on the railroad.

Still farther south, one-half mile west of Woodville, by the roadside, is a similar fine-grained massive rock, in which the eye just detects abundant squarish hornblende grains and rare plagioclase prisms. In the slide the hornblende grains are like those in other slides of this diorite, but here and there distinct augite centers appear, and some of the saussuritized feldspars show distinct banding with extinctions of 13° to 16° on either side the twinning plane.

Another rock of the same type is found in what appears to be a dike at the northern foot of Copper Mine Hill, on the northern border of the green schist area at the contact of the schist and the granite. It is a fine-grained, traplike rock containing much magnetite in feathery crystal groups, but showing no trace of leucoxene. The large square anhedra of green hornblende show low pleochroism. The rock, as a whole, is distinctly gabbrolike in structure, and these hornblendes occupy about the position of the original bisilicate, while the intervening stout feldspar blades retain their boundaries intact, although internally they are largely saussuritized, but show rarely broad twinning bands which extinguish at 10° on either side.

IGNEOUS ROCKS OF POST-CAMBRIAN (PRE-CARBONIFEROUS) AGE.

MILFORD GRANITE.

General description.—A great granite area (batholith) of a constant type that extends across Massachusetts and Rhode Island in the western part of the area here studied has been named by the writers from the well-known quarries in Milford, Mass.

This is a compact, massive rock, somewhat above medium grain, and of light color. The light flesh color of the feldspar and the blue of the quartz give it in some places a slight pinkish tint, and it is now much used as a structural stone under the name "pink granite." It differs from the Quincy granite, found farther east, in lacking hornblende and also in the fact that it is unaccompanied by the many varieties of rock that accompany that granite (porphyries, felsites, and breccias), and it differs from the rocks of many other groups that cross Massachusetts farther west by the lack of coarse porphyritic varieties.

Its two especially characteristic constituents constantly present are blue quartz and a microcline microperthite in which the albite is always dusted with minute crystals of muscovite and epidote, especially centrally, while the microcline is free from these minerals. These perthitic bands of albite also generally extend out beyond the surface of the microcline and cover it with a more or less continuous veneer. The rock also shows a fine micrographic structure in contact with quartz.

The feldspars project idiomorphically into large fields of quartz, which seem to have been single grains but are now somewhat cracked. Most of this quartz is blue, and this color appears also in the contact zones and even in the secondary quartz that is found in fragments of schist which are inclosed in the granite and which have been greatly altered by it. The fractured grains of quartz show with polarized light the strongest undulatory extinction, which indicates a state of strain that has probably produced the blue color.

The biotite is in small amount, and is here and there associated with epidote grains. In specimens of granite taken at the quarries at Graniteville it is evenly distributed or gathered in small blotches, as in the Milford type, and the rock in these quarries can hardly be distinguished from the Milford granite. In the northwest portion of the area, near Woonsocket, the biotite occurs in distant, interrupted, rudely parallel films, as in the rock at the Fayville quarries, north of Milford. In granite from a point south of Woonsocket the central portions of the spots and bands of albite in the microcline are crowded with muscovite crystals more strikingly than in the rock at Fayville. The albite is in coarser bands in and around the microcline and is filled with much larger scales of muscovite.

The granite from the country north of Spencer Hill, in Warwick, is a rather coarse subporphyritic rock, without blue quartz. The large, perfect, microcline microperthite crystals are characteristic, and in one specimen of this rock a soda orthoclase was observed. It contains rarely garnet, and the distinct feldspars and large quartz grains give it a porphyritic aspect.

It will long be difficult to separate the pre-Cambrian porphyritic granite-gneiss (the Northbridge gneiss) from the post-Cambrian and pre-Carboniferous coarse porphyritic granites, like those on the south end of Conanicut, and the coarse, subporphyritic granite of the Milford type.

The dark contact granite.—In a zone that is at some places one-half mile wide, surrounding the green schists, the rock is generally present in contact facies of considerable variety. The first sign of approach to the green schist is in the increase of biotite, causing a darker color. Thus the rock becomes more or less foliated and jointed, and near the schist it is distinctly and at times decidedly hornblendic. In the hills west of Providence the included fragments of the schists become so abundant that they occupy more of the surface than the granite, and farther west is a band in which the green schist is cut in every direction by great numbers of small granite veins. For this reason a broad area between granite and green schist could be mapped only as a contact zone between the two.

The dark granite near the contact north of Woodville is full of beautiful titanite crystals 1 to 2 millimeters long, of the regular "envelope" shape, and of dark aureoles around zircon.

Where the Milford granite is in contact with limestone, as west of Lonsville, the dark border is wanting. Here, however, the rock is very fine grained near the limestone. From a point 1 mile west of Copper Mine Hill its contact with the riebeckite porphyry can be well observed for a long distance. Both rocks are normal up to the boundary and neither sends out branches into the other. This more basic granite is apparently in part due to an endomorphic contact change within the limits of the eruptive mass of the Milford granite. This change appears to have been an enrichment with iron which may be explained as in part a differentiation of the granitic magma and a transference of the iron to the border, and as in part an absorption of so much of the ferruginous green schist that the rock has become more basic and darker. This interpretation is supported by the fact that granite of this type is not found at the contact of the Milford rock with limestone, quartzite, and porphyry. Along the boundary line of the granite and schist many good-sized fragments of much-altered green schist are inclosed in the granite.

DIKE ROCKS.

Aplite.—A very interesting dike of aplite, only one-half inch across, cuts the 2½-foot odinite dike in the eastern Lime Rock quarry, west of Lime Rock, and is continued beyond through the limestone. It is a bluish-white, fine-grained rock, only slightly different from the marble in appearance, as it contains many calcite grains. It is made up wholly of rounded grains of feldspar, part of which is plagioclase, sometimes twinned in broad bands, and having low extinction angles. It contains much microcline, and perhaps orthoclase. Mica and ore are absent, and radiated wisps of tremolite needles are scattered through the rock. Quartz is present only in the abundant micrographic portion. Scattered through the rock, in irregular grains, many of them of large size, is a very large quantity of calcite which has been taken up from the limestone, dissolved and recrystallized in the magma, since it is intercrystallized with the plagioclase and included in it, and is of different size and shape from the grains of calcite of the marble.

At the border of the aplite and the amphibolite, wisps of hornblende of much larger size than that of the average of the amphibolite project into the aplite.

There is also a 4-inch aplite dike in the limestone at the eastern Lime Rock quarry, but under the microscope it shows a texture that is very different from that of the rock already described. The half-inch dike is a very fine and even-grained microgranite with many small grains of microcline, curiously abundant micrographic intergrowth, no mica and no alteration. The 4-inch dike is coarser grained, with micrographitic texture, except for large grains of plagioclase (albite to

oligoclase), with centers made opaque by the great mass of white mica scales developed in them, and a few large grains of microcline.

Pyritous aplite.—Another interesting dike of the same type as the last runs across the path that goes up from the south end of the same Lime Rock quarry. It is 8 inches wide, and is composed of a clear, rather dark-gray, aphanitic rock of harsh feel, broken up into half-inch plates crusted on all sides by cubes of pyrite, which also appears elsewhere in the rock, though in less quantity. It effervesces very actively with acid. When this rock is examined with a power of 85 the field is seen to be covered with many opaque white spots, which may be leucoxene or kaolin. With polarized light much of the surface is seen to be covered with irregular-lobed areas of calcite, which may have been derived from the limestone, but if so have crystallized in places in peculiar lobate shapes. Except for this calcite, the field is strewn about equally with minute low-polarizing plates, which seem to rest in an almost apolar ground, and which take up about half the surface. With a power of 230 the apolar places are seen to be occupied by overlapping plates of the same colorless low-polarizing material. This seems all to be a fine-grained mosaic of orthoclase, and in the larger plates are seen here and there more brightly polarizing plates of muscovite, and the opaque white areas which cluster round the larger orthoclase grains seem with the higher power to be distinctly kaolin derived from its decomposition. The rock is thus an aplite, and its bluish-gray color is caused by its very exceptional content of pyrite. All these small dikes are interesting as possible members of the distant East Greenwich group described below, and as similar micrographic and microgranitic types occur in the Quincy group they suggest a connection between the two. Its abundant content of coarse microcline, however, seems to ally this rock more closely with the Milford granite.

BASIC ERUPTIVES.

Gabbro.—A great range of gabbro and syenite hills and isolated bosses, which have not been described in detail, extends southwestward along the south side of the Norfolk County basin from Canton Junction[a] to Wrentham. The remarkable mass of cumberlandite in Cumberland Hill lies in the extension of this range. This hill stands just on the northern border of the area here mapped and probably enters it beneath the drift. It has been fully described by Woodworth.[b] It is largely coarse massive menaccanite with a few porphyritic plagioclase phenocrysts. Where bronzite and plagioclase appear abundantly in the menaccanite mass it becomes a gabbro.

[a] Woodworth, J. B., Geology of the Narragansett basin: Mon. U. S. Geol. Survey, vol. 33, 1899, p. 118.
[b] Bull. Mus. Comp. Zool., vol. 1, p. 183; Proc. Boston Soc. Nat. Hist., vol. 21, p. 195.

In the prolongation of the range to the southwest an ideal gabbro of the same type, of coarse grain and wholly massive, occurs in a large bowlder on the hill a half mile northeast of Albion. This was probably brought by the ice from some point 5° or 10° west of north but near at hand, since in the sheet farther south, which we have studied in detail, this type is not found. It is a dull, dark rock, with spots of a faint shade of brown or green, large squarish areas of a brownish pyroxenic mineral, and large, shining, striated plagioclase cleavages and grains of menaccanite.

The slide shows a ground of coarse-grained labradorite, with maximum extinction in the albite twinning of 23°, and with the twinning bands rigidly parallel. The second original mineral is bronzite, which is abundantly dusted with black grains. It was formerly present in large squarish fields, which are now wholly or mostly changed into a coarse radiate fibrous mass of a bluish-green hornblende, in which a=ochre yellow, b=pure green, c=deep blue; $c<b>a$. Outside this there is around many of the fields a rim of an oil-green, scarcely polarizing mineral full of black dust and calcite grains, which has the aspect of a serpentine. Outside this, against the plagioclase, is a second rim, perhaps a reaction rim, of white, brightly shining plates like muscovite or paragonite, which have eaten into the plagioclase. A few large garnet grains occur.

The large menaccanite plates are cracked and are surrounded by a rim of biotite in large plates full of rounded scales of menaccanite like those common in the bronzite. They are gathered centrally and arranged in curved, beaded bands. There is no leucoxene or rust; no strain or crushing of constituents, and thus no dynamic metamorphism. The change went on without motion of part on part, and without oxygen; but water, silica, and alkali were needed to change the labradorite into the shining white paragonite, the bronzite into the blue hornblende, and this into the chloritic or serpentinous mineral, and to develop biotite from the menaccanite.

Odinite.—It is noteworthy that beside the olivine-diabase dike described below from the Lime Rock marble quarry, which is remarkable for its freshness and for the sharp-cut completeness of all its crystals, there should run another dike, of about the same thickness (2½ feet) and with the same strike (N. 50° W.) and dip (60° NE.), of a dark, aphanitic trap which should prove under the microscope to be so unlike the other. It can be recognized in the quarry by the fact that it is cut by a half-inch aplite dike, and by its lighter gray color and more aphanitic and even texture, the minute porphyritic needles of plagioclase and glassy grains of olivine of the diabase being absent. Under the microscope it is found to be made up wholly, or almost wholly, of a confused network of hornblende needles, all very minute,

so that it requires high power of the microscope to study it. The whole field has much more the aspect of a common, fine-grained hornblende schist of metamorphic origin than of an unchanged intrusive dike. The hornblende needles are ragged-edged and fibrous, so that a surface rarely shows a common polarizing color, and a basal section is made up of a bundle of diamond-shaped rods. This hornblende has very faint pleochroism; a=pale yellow, b=yellowish-green, c=pale bluish, b showing the strongest absorption.

This rock contains some large crystals of hornblende of the same type as the others. With the finer hornblende is intermixed over irregular and isolated patches a biotite that occurs here and there in parallel or radiate forms. This biotite is salmon-colored parallel to axis c, and nearly colorless in other directions. It is at some places changed into a pale-green chlorite. The rock contains a few menaccanite grains, most of which are surrounded by leucoxene, and many of the larger green hornblendes are centrally dusted with menaccanite grains and plates. Small areas of feldspar appear in the interstices between the hornblende needles. These are indeterminate because they are without cleavage or twinning, but have almost the same refractive index as the Canada balsam of the slide, or a little higher, and so are probably near oligoclase. This is probably the same dike that is described as amphibolite and figured from the southernmost limestone locality at Lincoln by Prof. J. B. Woodworth,[a] because its parts have been disconnected by faulting in the limestone, while all trace of these faults has disappeared from the adjacent limestone. He notes hornblende, chlorite, muscovite, titanite, magnetite, apatite, and quartz as constituents of this rock, and considers it, probably, an altered diabase. It bears considerable resemblance to the diorite in the serpentine hill directly north of the quarry, and may possibly be an apophysis of this rock. It is massive and unstrained, and has not suffered any dynamic change except the slight displacement which it and the limestone experienced together. Its walls against the limestone are intact. It does not effervesce with acid, and it seems to me possible that the only change since consolidation may be the chloritization of a part of the biotite and the growth of the leucoxene around the menaccanite. The central crowding of the hornblendes with black ore grains may be an original structure.

If the rock has suffered only the amount of change indicated above, it may be called an odinite and be associated with the gabbros of the region. It was intruded in the limestone after these had been metamorphosed, and is cut by the aplite which is here associated with the Milford granite.

[a] Geology of the Narragansett basin: Mon. U. S. Geol. Survey, vol. 33, 1899, p. 108.

IGNEOUS ROCKS OF PRE-CARBONIFEROUS OR EARLY CARBONIFEROUS AGE.

SUBDIVISIONS.

The newer acid eruptive rocks, which occupy a large portion of the area mapped, may be conveniently divided into two large groups:

(1) The hornblende granites and granite porphyries in Cumberland on the northeast, which may be considered a southern prolongation of the granite and porphyry series that extends southward from Ipswich across the Boston basin and includes, in the middle of its extent, the large quarries at Quincy, from which these rocks may be called the Quincy group.

(2) The East Greenwich group of biotite-granite porphyries and graphic microgranites and the brecciated phases of the latter. It is a question whether this should be regarded as a southward prolongation of the Quincy or as an independent group. The rocks of the two groups show only partial resemblances.

QUINCY GRANITIC GROUP.

DISTRIBUTION AND GENERAL CHARACTER.

The rocks of the Quincy granitic group occupy the whole area between the green schist and the Carboniferous rocks along the northeastern border of the green schist from Diamond Hill southward to Berkeley, forming a southern lobe of the broad Quincy band in the Boston basin.

The commonest rock in the central parts, notably in all the large central lobes 2 miles south of Diamond Hill, is a coarse, light porphyritic granite with a few squarish feldspar phenocrysts two-thirds of an inch long—almost a granite porphyry, with here and there limpid quartz phenocrysts inclosing lobes of a microgranitic base.

A second type is a granite porphyry in which all the constituents are of dark-gray color, and the porphyritic character, although perfectly developed, comes out most distinctly only on weathered surfaces or under the microscope. At one extreme it is a rather fine-grained rock with abundant small square feldspars and dark-blue rounded but distinct primary quartz phenocrysts; at the other extreme it is a very peculiar rock, made up almost entirely of square feldspars (2 to 4 mm. across), the quartz appearing only in the microgranitic groundmass. An identical rock appears in the great Cumberland dike 1 mile west, and a similar dike occurs 1 mile west of Lonsdale, 2 miles south of the southernmost area of the granite porphyry, this occurrence serving to lessen the gap that separates this rock from those of the East Greenwich group.

A third and most interesting type is a riebeckite porphyry and granite in which the large rounded phenocrysts of quartz and smaller

squares of feldspar are inclosed in a micrographitic base that is at some places of a purplish tint, from the content of fluorspar grains and blue riebeckite needles. This forms a compact area along the north edge of the area mapped in Pl. I, and extends for an unknown distance northward.

A fourth type, forming the border rock near the green schist, is a bluish-white microgranite. This appears only along the south side of the southern separate area between Hunting Hill and Berkeley. In the western portion of this southern area is a fifth type—a dark, hornblendic granite—and a dark chloritic facies of the same rock appears in a small patch at the border of the granite west of Diamond Hill.

The boundaries of the subdivisions as shown on the map (Pl. I) are only approximately exact, as these subdivisions were fixed after the field work was completed, partly by study of the material collected, and so no sharp, definitely marked boundary lines are drawn. Full notes and sufficient material were taken in the course of the field work, but much of the area is covered by till, and the determination of the nature of the underlying rock at some places is therefore difficult and doubtful.

PETROGRAPHIC DESCRIPTIONS.

Granite porphyry.—The granite porphyry occurring along the east branch of Sneech Brook in Cumberland (slide 359) and that of the Cumberland dike is a dull-black rock, with dark square feldspars and quartz crystals, generally smoky, but in a section (slide 371) from the north end of the dike the quartz was bipyramidal and of blue color. It was limpid, without microlitic inclusions, and with deep lobes of the light-gray microgranitic ground. The feldspar was untwinned soda orthoclase, and showed extinction of 12° on M (010) and the vertical emergence of a positive bisectrix. Some of the feldspars inclose great numbers of large, stout, sharply rectangular rods of an acid plagioclase. These rods are singly twinned with small angle, have the suture parallel to the side of the square, and show a higher index of refraction and birefringence than their host. The feldspar also in places incloses many lobes of the groundmass. The microgranitic ground contains quartz, feldspar, magnetite, biotite, muscovite, and calcite.

The rock shows distinctly a fluidal structure, and some specimens carry fluorite. It incloses fragments of a calcareous sandstone so full of fluorite as to impart to it a deep purple tinge. Where it lies in contact with the green schist this is only slightly indulated, but is soaked full of purple fluorite for one-half inch from the boundary. At the north end of the Cumberland dike the rock contains an inclusion of the coarse white granite of this series, which was also full of

purple fluorite. A slide (384) cut from the rock adjacent to an inclusion of calcareous sandstone shows fluidal structure, adjacent phenocrysts being connected by bands of a much coarser groundmass, and so united into somewhat parallel trains. In this coarser groundmass many of the grains are fresh untwinned and unstained calcite that include and are included by the other constituents so that they appear to be an original constituent. Calcite is much rarer in the intervening fine-grained ground, but at some places trains of groups of calcite grains run through this also, each group being surrounded by a dense halo of black ore grains. These calcite grains are wholly unlike the calcite of the inclusions. In one slide an exceptionally large calcite grain is partly inclosed by a large phenocryst of soda orthoclase. The calcite must therefore have crystallized out early in the magma before the feldspar phenocrysts had been completely formed or the black ore had solidified. The latter is almost wanting in the phenocrysts, and was formed by a reaction of the carbonate and the iron-bearing solutions in the magma. Most of the grades that have the same shade as the large grains are also calcite.

There is another dike of the granite porphyry in the green schist by the schoolhouse 1½ miles west of Lonsdale, near the Moshassuck River, in Lincoln. It is 20 feet wide, with sharp boundaries. Under the microscope the rock (slide 402) shows the extreme of alteration without the slightest disturbance of its original structure. The feldspars are wholly idiomorphic and are set so closely together that there is but little interstitial material. These feldspars are in places changed to a congeries of epidote crystals without losing the original sharpness of boundary.

The groundmass shows micrographic structure where it borders the feldspars, from which the quartz rods radiate, and this structure passes into a microgranitic arrangement at the center of the interspaces. The abundant biotite is largely chloritized. This rock differs from that of the Cumberland dike in its greater quantity of feldspar and in the absence of large quartz phenocrysts of first consolidation.

Riebeckite porphyry.—The riebeckite porphyry is a fine-grained granite porphyry made up largely of small, square feldspars, larger rounded or bipyramidal quartz grains, and black amphibole (riebeckite) blades, these three constituents being embedded in a microgranitic ground which looks like a fine, white quartzite.

The feldspars are Manebach twins of orthoclase microperthite, with broad anastomosing bands of albite in places in peglike arrangement; extinction, 16½° on (010). In places these bands coalesce at the surface to form broad continuous layers of albite. Some of them are dusted full of long needles of riebeckite. Others have the moiré surface and the optical character of soda orthoclase. The large quartz grains, some of which are bluish, are nearly all idiomorphic

and have all the characteristics of porphyry quartz. They are limpid and show slight strain and sharp straight lines of cleavage and cavities with moving bubbles. They are penetrated by deep lobes of the fine, granular quartz-feldspar ground, which as a micrographitic groundmass also incloses the other constituents.

Riebeckite is present not only in the many microlites that penetrate the feldspar and are absent from the quartz, but in blades that inclose large angular grains of orthoclase. The mineral has the very strongest absorption: a = deep blue, b = dark greenish blue, c = yellow-brown; $a>b>c$. It has perfect prismatic and basal cleavage.

Purple fluorite is an interesting original constituent of the porphyry. It is found in rather large grains, especially in the vicinity of the riebeckite, and its presence may have determined the formation of the riebeckite rather than another form of hornblende or augite.[a] The best locality to study the rock is on the hill a mile southeast of Copper Mine Hill, in Cumberland.

Along its southern border, on the north slope of Copper Mine Hill, the rock retains its texture, except that all the iron has gone into magnetite. On page 66 is given an analysis of the riebeckite porphyry, and for comparison one of the riebeckite granite of the Hardwick quarry at Quincy, Mass.

White's description and figure of the rock of the Weymouth Fore River in the Quincy basin,[b] north of the area here studied, agree closely with that of the rock here discussed.

The "crocidolite" announced in 1879[c] and described in 1887[d] by A. H. Chester and F. I. Cairns from "Beacon Pole Hill,"[e] would seem to be the same mineral that we have here determined optically to be riebeckite. It occurs in seams in a granite ledge.

> It is usually disseminated in fine particles through feldspar but often occurs in large masses up to the size of a butternut. Unbroken surfaces sometimes present a botryoidal appearance, and the nodules, when broken, show a radiated structure. * * * Its color is usually a dark bluish gray, the radiated nodules, however, being darker, almost an indigo blue. It is associated with dolomite, glassy quartz, and rarely with light purple fluorite.[f]

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[a] This suggestion has been independently developed as the result of an extended study of the riebeckite rocks by Mr. Murgucci in a paper read before the Geological Society in Philadelphia in December, 1904. (See Am. Jour. Sci., 4th ser., vol. 20, 1905, p. 133.)

[b] White, T. G., Contribution to petrography of the Boston basin: Proc. Boston Soc. Nat. Hist., vol. 28, 1899, p. 132, Pl. IV, fig. 12.

[c] Dana, Man. Min. and Lith., 3d ed., p. 252.

[d] Am. Jour. Sci., 3d ser., vol. 34, p. 108.

[e] This is the hill on the north edge of the area mapped northeast of Copper Mine Hill, which is apparently the Tower Hill of Shepard, cited above, and the Cumberland Hill of Chester and Cairns.

[f] Chester, A. H., and Cairns, F. I., Crocidolite from Cumberland, R. I.: Am. Jour. Sci., 3d ser., vol. 34, 1887, p. 108.

Analyses of "crocidolite."

	I.	II.		I.	II.
SiO_2	53.13	51.03	Na_2O	6.26	6.41
Fe_2O_3	15.93	17.88	H_2O	3.95	3.64
FeO	21.25	21.19			
MgO	0.22	0.09	Total	100.74	100.24

Hornblende granite.—A hornblende granite occurs abundantly in the southern area between Berkeley and Hunting Hill. It is dark, coarse, massive, and fresh looking, varying from a rock resembling a gabbro, in which the large feldspar and biotite phenocrysts and grains stand out on a greenish-black ground, to a more granitic facies, in which, on the dark mottled surface, the large black hornblende phenocrysts are relieved by a white border and many of them luster-mottled by large apatite crystals.

Slides of rock of both these types (366, 361) have under a lens an identical and very characteristic appearance. The magnetite, biotite, and hornblende, all of which occur in small amount, are massed in groups and more or less altered. The whole field seems to be made up of closely packed feldspar crystals of uniform size and shape, having perfect crystal faces except against the hornblende-biotite groups, and the small amount of limpid quartz is arranged in narrow areas between these crystals. They are uniformly Carlsbad twins of soda orthoclase, which, except around a narrow border band, are dusted full of perfect crystals and crystal groups of almost colorless hornblende, epidote, and garnets, the latter in model-like dodecahedra.

The quartz is free from inclusions, granulation, or strain, and some crystals are of bipyramidal shape. The rock has thus the texture of a porphyry without a groundmass. The quartz in the center of the intersertal fields shows, where it adjoins the feldspar, a micrographic and microgranitic texture.

A similar rock on the west side of Diamond Hill has a more mashed and chloritized aspect and is probably adjacent to a fault. The slide (357) shows the feldspars to be a dense mass of overlapping blades of hornblende and epidote. The quartz is slightly strained and granulated and the biotite is chloritized. The rock contains the same abundance of large apatites and the same peculiar model-like garnets that were noted by Woodworth in the corresponding hornblende granite from the Cambrian area on Hoppin Hill, in Attleboro.

Microgranite.—The microgranite is a light pearl-gray rock of very fine grain, with a slight banding, due probably to flow structure. It is a mixture of granular quartz and microcline, which in some specimens of the rock interlock so completely as to produce almost a micrographic structure. The gray color is due to small grains of magnetite and biotite. (Slide 353.) It resembles very closely the microgranite

of East Greenwich. (See p. 62.) It can be studied along the road southwest of Hunting Hill.

Vein quartz at Diamond Hill.—The enormous mass of vein quartz at Diamond Hill, only the southern half of which is shown on the map, lies on the border between the Carboniferous sediments and the granite porphyries. In the continuation of this mass to the north, beyond the limits of the area mapped in Pl. I, Professor Woodworth has mapped a large area of felsite, which he assigns to the same age as that of the felsites around Attleboro. According to his determination [a] the quartz was deposited by hot springs connected with the volcanic activity of which the felsites are the product, and its formation was therefore contemporaneous with that of the earlier Carboniferous beds in this area. This seems to be the only possible explanation of the great veinstone body. The mass is made up of many layers of quartz, much of which occurs in radiating crystals, suggesting diamond, and from these the hill gets its name. The mass comprises also much white compact and chalcedonic quartz.

Phosphate of lime and red hematite occur in beautiful botryoidal and stalactitic groups in the quartz on the southern slope of Diamond Hill. [b]

Mr. George F. Kunz writes as follows concerning the varieties of quartz found at this locality:

> The highly modified crystals from Diamond Hill and Cumberland Hill, Rhode Island, also the fine ones from White Plains and Stony Point, Alexander County, and from Catawba and Burke counties, N. C., are worthy of mention, and lately formed the subject of a crystallographic memoir by Prof. Gerhard vom Rath. [c]
>
> Jasper agate is found in considerable quantity at Diamond Hill, Cumberland, R. I., in all shades of white, yellow, red, and green; these colors are also all intermixed in one specimen, usually mottled, and at times beautifully banded in irregular seams of white, creamy brown, greenish, and brecciated. It is found in large quantities, and although fully 1,000 pounds is taken away every year by visitors and collectors not over $100 worth is sold or polished per annum.[d]

"WAMSUTTA GROUP" OF WOODWORTH.

The group of granite porphyries, felsites, and fine graphic granites described by Professor Woodworth,[e] the border of which makes a great curve in the "Wamsutta group" of Carboniferous beds from North Attleboro by Lanesville to Arnolds Mill is most interesting. The curve may perhaps be continued to include the larger granite-porphyry area at Diamond Hill. It conforms with the Carboniferous beds in their folding around the central Cambrian island. The rocks of this group are accompanied by a series of basic dikes. The larger felsitic mass has some of the characteristics of a tilted laccolith.

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[a] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 155.
[b] Jackson, loc. cit., p. 52.
[c] Mineral Resources U. S. for 1883 and 1884, p. 749.
[d] Op. cit., p. 762.
[e] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 153, and map (Pl. XVII).

There is frequent flow structure, with crumpled layers, and beneath the massive flow of felsite is a bed wherein the same felsite is the matrix of an agglomerate of rounded pebbles of felsite, granite porphyry, quartzite, and hornblende granite. Professor Woodworth states that "the peculiar features of the Wamsutta series * * * point to a volcano or volcanoes existing in this field in Carboniferous time," and compares the rocks with the flows and intrusives of the quartz-porphyry series in the Boston basin. He speaks of "Wamsutta volcanoes," and connects the intrusive granite porphyries described above with the effusive felsites and granite porphyries of the "Wamsutta series," and finds the same story repeated in the Blue Hills region on the north side of the Norfolk County basin, and still farther north in the larger felsite area about Boston.[a] He mentions and maps an area of granite porphyry, about 2 miles long, north of the quartz veinstone mass of Diamond Hill.[b] This is possibly the northern apex of the area shown on Pl. I. Another somewhat smaller area lies farther east, within the limits of the Carboniferous, one-half mile northwest of Arnolds Mill. The rock from this area contains rare microscopic garnet and fluid inclusions with moving bubbles. Professor Woodworth associates these two stocks of granite porphyry with the adjacent felsites, which are clearly interbedded with the Carboniferous, and therefore deduces the probable Carboniferous age of the whole series of the granite porphyries extending from this region to the vicinity of Boston, including the rocks in Cumberland. This is doubtless the most probable relation, but no certain evidence was found along the border between the granite porphyry and the Carboniferous to indicate that the granite porphyry was intruded into the Carboniferous, nor does Professor Woodworth adduce such evidence.

The felsite of Diamond Hill is unlike anything in the Quincy and East Greenwich groups. A sample taken from the northeast slope of the hill is a light pearl-gray rock, breaking in plates, and wholly aphanitic and hornstonelike. It fuses easily to a white enamel. The microscope shows a few small, angular kaolin spots, which are traces of former feldspar crystals, and minute quartz veins, in a uniform microfelsitic base of exceedingly minute plates and short needles, which polarize brightly and lie apparently in a colorless glass. There is no iron oxide. This rock is precisely like the felsite in slides taken from rock at Natick, Mass., in the middle of the Boston basin.

The granite mass in Cumberland forms the southern end of an extensive belt of igneous rocks, the main body of which lies north of the area mapped in Pl. I. The felsites (aporhyolites) of the Boston basin approach this area at the northeast base of Diamond Hill and swing round the Cambrian area in the "Wamsutta" region to the east.

[a] Idem, pp. 155-156.

[b] Mon. U. S. Geol. Survey, vol. 33, 1899, pp. 117, 155.

Distinct surface flows are therefore not found in this southern extension of the Quincy rocks. The content of riebeckite and soda orthoclase connects the series with the Quincy granite. Eleolite found in the Essex basin is lacking here, but a nepheline tephrite occurs at a point not much farther west, at Fairmount Farms, in Woonsocket. (Slide 25920 of the Tenth Census rocks.)

Microgranite also is common in both groups. The hornblende granite described above, which might almost be called a granite porphyry, is much like the granite porphyry of the "Wamsutta" region. Both contain beautiful microscopic garnet. There is also a close resemblance between the porphyry and the micrgranite of the Cumberland area and the corresponding rocks of the East Greenwich group described below, though hornblende is lacking in the latter and the limited dark border beds are biotitic.

EAST GREENWICH GROUP.

DISTRIBUTION AND GENERAL FEATURES.

The East Greenwich group of eruptives became interesting in the course of this survey because of the discovery that it carries the porphyries and fine graphic granites of the Boston basin much farther south than they have been known before.

A dozen broad bands of acid eruptive rocks cross the State of Massachusetts from north to south, either as continuous areas or in rows of great batholiths. Each band has many distinguishing characteristics. Porphyries and basic rocks are rare or for the most part wholly lacking in all of these bands that lie west of the broad easternmost band which extends southward from Ipswich across the Boston basin. In this belt porphyries and a great range of basic rocks accompany the granites. Professor Woodworth has connected the porphyries of the adjacent "Wamsutta group" with the porphyries and felsites of the Boston basin, and the porphyries of the two groups described in the present report show many points of resemblance to each other, to those of the "Wamsutta group," and to those of other members of the same band farther north, and, although isolated in surface occurrence from the rocks of the Boston basin, they seem to represent a southward prolongation of those rocks.

Much of the country occupied by the East Greenwich group, especially its central and most interesting portion, is covered by till, and the contact relations can be observed at only a few places. This group includes granite porphyry, some of it carrying rather small phenocrysts, micrograinite, a massive and banded fine-grained micrographic rock, and a breccia formed of a great mass of angular fragments of all sizes of the latter rock, either alone or inclosed in the granite porphyry. A black biotite granite occurs in small amount on

the border. A distinguishing common characteristic is the micrographic and micrographic groundmass. The former is even-granular, like a fine sandstone. Its grains become in places more and more lobate and interlocking until a continuous micrographic texture is produced. The microgranite appears in purity over large areas; the micrographic rock appears mostly as fragments in the breccia. Where quartz and microcline crystals appear in abundance in a much finer microgranitic groundmass porphyry is produced, and appears in continuous masses and as the paste of the graphic microgranite breccia. Thus where phenocrysts become predominant and the microgranitic groundmass is interstitial or absent we have granite porphyry and granite, an intermediate type occurring where the microcline wholly predominates. At the border these peculiarities are masked by the abundance of biotite in the black contact granite.

PETROGRAPHIC DESCRIPTIONS.

Granite and granite porphyry.—The granite of the East Greenwich series is always in aspect allied to granite porphyry. The feldspar and quartz are more or less idiomorphic and are inclosed in a small amount of granitic ground of rather fine grain. Where the small flesh-colored feldspars grow more distant and distinct and the rounded blue-quartz grains more individualized the rock becomes a granite porphyry; which is the prevailing form of rock in the areas mapped as granite and granite porphyry.

Another variety is found only in large bowlders at the quarry in the village of East Greenwich. Large flesh-colored feldspars an inch long and large blue-quartz grains appear in a rather coarse microgranitic ground, and great oval and parallel blotches of biotite cover rude foliation faces.

At the extreme south end of the granite porphyry a specimen was obtained which showed its contact with the light-gray microgranite, and the contact was a rather sharp one, though more like a pronounced schlieren contact than an eruptive contact. This seems to indicate that the granite porphyry was consolidated a little later than the other because it is free from biotite and is distinctly coarser for a quarter of an inch from the contact.

Basic border of the granite porphyry.—Along the northern border of the granite porphyry of the East Greenwich group on Bald Hill in Warwick, separating it from the Cambrian quartzite, stretches a band, about 40 rods wide, of heavy black subporphyritic rock, which is in places spotted white with feldspar crystals and groups of crystals. It is of medium grain, and its dark color is due to its abundant content of biotite and magnetite. It is well exposed along the southern slope of Bald Hill and crosses the road just east of the hill, where it is slightly gneissoid. It grades at many points into the granite porphyry, the

gradation showing that the two are parts of one mass. At some places the boundary of the two rocks is intrusive, the granite porphyry being the newer rock. At some localities the granite porphyry is unchanged up to the contact, though in other places it becomes finer grained in a belt several inches wide.

The black granite is cut by many small dikes of graphic microgranite or of microgranite containing small crystals of pyrite, and by one small dike of granite porphyry.

Rarely a fragment of the Cambrian quartzite is found inclosed in the granite. It is clear that this pure quartzite can not have supplied the iron to the border granite, which must be regarded as a basic border differentiate of the granite porphyry. The same brown garnets are found in both. As shown in several slides, the feldspars have the same idiomorphic character, and the graphic structure is abundantly developed in both.

A slide (652) shows a vein of graphic microgranite crossing at the top and a portion of the black granite below. A large idiomorphic feldspar in the center of the field extinguished as a single individual, but is dusted so full of minute crystals of an epidotic mineral and of micrographic quartz as to produce the effect of aggregate polarization. Dark spots are biotite aggregates. The slide shows with the lens so many well-defined feldspar crystals that it can be called a granite porphyry, though its porphyritic character is disguised by the abundant biotite. The vein of micrographic texture is very interesting. It is about 2 millimeters wide; has a central suture. It is white, and thus stands out clearly against the black granite. In thin section the micrographic structure of the black granite is seen to be continued into the white vein, in which it grows inward from both sides of the vein with a coarser texture than in the granite and meets along the central suture. This minute vein, which is free from the abundant epidote dust as well as the dark minerals that fill all the rest of the rock, is analogous to the limpid pertlitic aftergrowth of many of the epidote-filled nuclei of the feldspars. The same slide contains a wider dike of microgranite.

The black granite is thus of the same type as the other members of the series, but is slightly older and is cut by veins or small dikes of them all.

Blue-quartz-microcline porphyry.—The porphyry from the important locality one-half mile southeast of the top of Spencer Hill is a fresh rock with a bluish to chocolate-colored base, just resolvable with the lens into a granular mass. It contains pale flesh-colored feldspars two or more millimeters long; large, clear, blue-quartz phenocrysts, and black biotite scales just visible with the lens. The feldspar groups show small miarolitic cavities. An analysis of this rock is given on page 66.

Under the microscope the quartz crystals are the most prominent and abundant (see fig. 5.) They have often perfect forms, with prism and double pyramid; they are free from inclosures but are penetrated by lobes of the groundmass. Here and there two or three of these crystals are grouped together. Many of them are often fissured with perfect cleavage and polarized with fine broad undulation, indicating incipient strain. The large-lobed blebs of quartz in the feldspars and the quartz grains of the ground are full of magnetite grains.

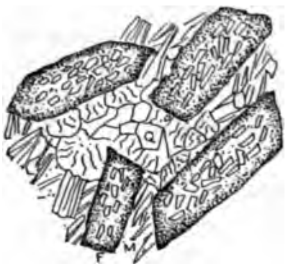

FIG. 5.—Crystals of feldspar embedded in quartz groundmass. F, Feldspar; M, magnetite; Q, quartz.

The feldspar is generally microcline. It showed with heavy solution the same specific gravity as the Ceylon moonstone. The microcline twinning is generally flamy and irregular, as shown in fig. 6. The composites are also twinned after the Carlsbad or Baveno law. Fig. 6 shows an upper crystal twinned to right and left with crystals on the Baveno law. There are also large included plates of bytownite in the large microcline, showing extinction −30 on M and emergence of an axis.

Biotite is regularly but distantly disseminated in the ground in long blades, many of them full of rounded quartz grains. Muscovite is

FIG. 6.—Microcline Baveno twin cut at right angles to a. Negative bisectrix nearly central. From quartz porphyry south of Spencer Hill.

abundant, in irregular plates surrounding the feldspar. Magnetite is more abundant, but occurs in smaller grains than the biotite. It is often in regular octahedra and arranged in long fluidal trains. The ground is micrographitic, and at some places shows fluidal structure. [illegible] feldspar ground a few of the feldspars show micropeg-

matitic structure, vermiform quartz rods penetrate the feldspar and themselves contain blebs of feldspar orientated with the host. A fine dust of magnetite in octahedra or in vermiform shapes is scattered through the ground. Zircons cause dark borders in the biotite.

Outside the locality named above, southeast of Spencer Hill, the porphyry is generally of lighter color, and a slight fissility is in places produced by the aggregation of the biotite into flattened concretionary groups. That portion of the porphyry which forms the cement of the extrusive graphic granite-porphyry breccia is the latest member of the series. In a block from the southern border of the porphyry, at its contact with the microgranite, the microgranite penetrates the porphyry in delicate lobes, as seen in thin section, and has a distinct differentiation border, which is black from the concentration of magnetite grains. This is apparently a slightly later dike of the microgranite, resembling those penetrating the black border granite.

Microgranite.—The microgranite is best exposed in the quarry in the northwest corner of East Greenwich village. It is a fine-grained aplitic rock, often splitting in slaty slabs of a fresh bluish-white to dark-gray color, in which the biotite scales are just visible. Macroscopically it is like the graphic microgranite, but is generally darker; microscopically it has a very regular automorphic granular texture. An analysis is given on page 66.

In some parts of its mass small quartz and feldspar phenocrysts form in the microgranite; in others the quartz becomes more abundant, occurring in spherical grains nearly the size of a pea—the unit form with rounded faces. This forms a transition to the blue-quartz porphyry. These transitional forms show under the microscope a limpid wavy polarizing quartz, as in the porphyry. Seen with low powers the feldspar seems to be untwinned, but with high powers shows the finest laminæ. The feldspar is generally microcline. One section on M gave central positive bisectrix and extinction 11°, and is therefore soda orthoclase. It was full of long plates parallel to a steep positive orthodome of about 76°. Purple fluor occurs in the microgranite where it has been slightly sheared and has become banded with biotite.

The microgranite in the East Greenwich quarry has been partially crushed into flat fragments, which have been recemented by thin, black films of biotite, one of the many indications of the migration of the biotite. At some places the granite-porphyry cement of the breccia passes into this biotite facies by the disappearance of the quartz and feldspar phenocrysts, especially in thin layers, and the rock then generally becomes black near the contact from the great concentration of the magnetite in bands that may be an inch or more wide. The magnetite found in the conglomerate is probably derived from this rock, as the other constituents are mostly free from iron.

Microgranite or graphic microgranite.—The micrographic facies of the central granite mass is present in rather large amount, but mostly as a constituent of the breccia. It makes up some part of the rock mapped as microgranite, but can not well be separated without extensive microscopic work. Even at the East Greenwich quarry some slides are half micrographic in texture. It is a fine, even-grained rock, distinctly granular with the lens, bluish white, weathering pale fawn color. Under the microscope it is seen to be made up of rather large, rounded, or interlocking grains of orthoclase or microcline with exceedingly fine twinning structure, each grain filled with vermiform quartz rods in perfect micrographic structure, which are in places so abundant that they almost entirely mask the feldspar. Small, long plates of biotite are scattered evenly and distantly through the rock, which swarms with small octahedra of magnetite.

Many fragments of the graphic microgranite in the breccia, some over a foot across, show very distinct fluidal structure in the form of thin wavy bands of lighter and darker gray, and one of these fragments itself contains fragments, about an inch long, of micrographic texture, around which the fluidal bands bend. This banding is caused by the concentration of magnetite and biotite in zones and by the alternating narrow layers of micrographic and microgranitic rock.

An analysis of the graphic microgranite taken from a large fragment in the graphic microgranite breccia at a spring near Spencer Hill, at a locality described below, is given on page 66. It differs from the analysis of the microgranite mainly in showing the presence of the Fe_2O_3.

Dikes of microgranitic and micrographic texture.—Besides the large stocks of microgranite and graphic microgranite described in the preceding sections and designated on the map, there are many veins or small dikes of the same rock. A minute graphic microgranite dike in the dark granite seen in one slide is described on page 60. The same slide contains a vein or minute dike of microgranite. This constant association shows that the two types are closely allied. These dikes easily escape notice in the light-colored rocks, but are very abundant in the dark border granite and confirm the idea that it is the older rock. A dike of unusually coarse graphic microgranite, 2½ inches wide, was found on the border of this dark granite, where one wall was the normal granite porphyry and the other the dark fine-grained microgranite. One slide shows the microgranite in contact with the graphic microgranite which occupies the lower three-fourths of the slide. A large dark square at the bottom is a perfect crystal of soda orthoclase cut on M, and the nucleal crystal is full of microlites of a shining epidotic mineral, and is greatly enlarged outwardly by limpid and less twinned material in which the graphic structure first appears and is very marked.

A part of the same slide shows two dark adjoining miarolitic cavities, into which perfect crystal ends project, as well as forms with rounded crystal faces, to which the twin structure conforms, also projecting into the cavities. Both microcline and soda orthoclase appear.

Microclinite.—The Carboniferous conglomerate on the west slope of Spencer Hill contains grains of blue quartz and feldspar from the porphyry, grains of microgranite, and pebbles of Cambrian quartzite, as well as small pebbles of a very peculiar rock. This rock, here called microclinite, is made up wholly of large, squarish grains of microcline, all of about the same size and shape, which are filled full of magnetite in rounded grains and in beaded and branching growths that simulate very closely the micrographic texture of some of the granites. Muscovite in minute scales is present in the microcline in large amount, and assumes the same distribution as the black ore. Here and there is a bleb of quartz or a scale of biotite. There is no interstitial material between the interlocking grains of microcline, so the rock may be considered a form of microcline poryhyry, made up wholly of the feldspathic constituent, with secondary magnetite as the only important accessory.

The branching magnetite and muscovite growth penetrates the grain for a certain distance, and then halts abruptly in the middle of a row of microcline grains, as if the iron had been brought in from without, as in the Carboniferous conglomerate in Cranston. The magnetite grains are more abundant and larger in the mica-schist paste, but are at some places concentrated in a broad black band that passes through the microlinite.

Graphic microgranite breccia with granite-porphyry cement.—The microgranite is in places broken into thin, splintery fragments, which are cemented together by films of black biotite. This kind of fracturing occurs locally in the quarry in the northwest part of East Greenwich village, but only in a narrow layer, and the small fragments are only slightly moved upon one another.

The large area at Spencer Hill, in Warwick, which is represented on the map as about a mile square, is of much greater interest. The simplest form of this breccia occurs on the western slope of Spencer Hill, in the Kent quadrangle, just across the western boundary of the Narragansett Bay quadrangle, at a point south of a schoolhouse in latitude 41° 40′ 30″, longitude 71° 29′ 30″, and in the field to the east. It is a beautiful, fine-grained, mottled, pearl-gray rock, the angular fragments of graphic microgranite being cemented by thin films of magnetite and biotite. Here and there regular and partly rounded Cambrian quartzite fragments, 1 to 3 inches long, occur in the breccia, indicating that some part of the breccia must have formed near the surface, and that if the superincumbent beds had been pre-

served the rock would here show a transition upward into the Carboniferous conglomerate.

The most interesting form of the breccia occurs at a spring about 10 rods south of the road running south of Spencer Hill, in a depression just east of a house, latitude 41° 40′ 15″, longitude 71° 29′ 15″. In clearing the fields here large masses of the rock have been blasted to pieces, which afford samples of fresh rock for study. The breccia is made up of pearl-gray fragments of almost aphanitic graphic microgranite, ranging in size from fine dust to pieces a foot across. These fragments are mostly massive, but some large pieces show perfect fluidal structure and themselves inclose small fragments of massive graphic microgranite. These small fragments are cemented by a small quantity of a blue-quartz porphyry, which itself shows fluidal structure between the included pieces, marked by trains of magnetite grains that in some places pass through the large corroded biotite scales. This porphyry at some points at the border contains fluorite.

Small shining scales of biotite are abundant in the central portion of some of the micrographic fragments, but absent from the outer half inch. It may perhaps be assumed that the brecciation took place so soon after solidification that the porphyry filling the fissures reheated the graphic microgranite so that a resorption of the few scattered biotite grains took place. It may also be assumed that the cementing of the fragments with biotite or biotite and magnetite occurred at the same time in areas where the porphyry could not penetrate, but where, by pneumatolitic processes, superheated steam and other vapors carried the cementing minerals to their present position, and the same pneumatolitic process may have resorbed the biotite in the micrographic fragments.

The breccia also contains small pockets of granitic débris and large rounded cobbles of granite, from an inch to a foot in length. This granite is a medium-grained two-mica rock. The quartz and feldspar have a certain individuality; the feldspar is in small, perfect, opaque Carlsbad twins, and both quartz and feldspar are included in a small amount of fine ground, a characteristic that connects this rock with the granite porphyries described above.

CHEMICAL RELATIONS OF THE CARBONIFEROUS IGNEOUS ROCKS.

The analyses given below show the chemical composition of the igneous rocks of the two groups. Analyses of riebeckite-bearing granite from Quincy, Mass., and of the Milford granite are presented in columns V and VI for comparison.

Analyses of igneous rocks.

	I.	II.	III.	IV.	V.	VI.
SiO_2	76.81	74.52	77.35	73.01	73.93	77.08
Al_2O_3	10.57	10.07	10.89	11.23	12.29	12.54
Fe_2O_3	0.00	3.74	1.98	2.53	2.91	0.00
FeO	3.74	2.81	2.82	3.66	1.55	0.95
MnO	0.18	0.20	0.13	0.19	Trace.	....
MgO	0.05	0.01	0.09	0.02	0.04	0.01
CaO	0.32	0.86	0.70	0.75	0.31	0.75
Na_2O	3.42	3.88	4.24	5.56	4.66	3.64
K_2O	5.30	3.46	3.38	3.66	4.63	4.99
S	....	....	....	0.05	....	....
BaO	....	....	....	0.06	....	....
SrO	....	....	....	0.01	....	....
Li_2O	0.00	0.00	0.00	0.00	....	....
H_2O +	0.25	0.86	0.26	0.55	0.41	....
H_2O – 110°	0.00	0.07	0.05	0.00	0.18	....
	100.59	100.48	101.89	101.28	100.91	99.96

I. Microgranite. East Greenwich, R. I. From the quarry at the northwest corner of the village.

II. Graphic microgranite. East Greenwich, R. I. From the spring locality south of Spencer Hill, described on page 60.

III. Blue-quartz porphyry. East Greenwich, R. I. From a point a half mile southeast of the apex of Spencer Hill.

IV. Riebeckite porphyry. From top of hill 1 mile northeast of Sneech Pond, Cumberland River.

V. Riebeckite-bearing granite from Hardwick quarry, Quincy, Mass. Presented for comparison.

VI. Milford granite. (For comparison, see p. 45.)

Analysis I to IV, by J. H. Perry; analysis V, by Mr. H. S. Washington (Am. Jour. Sci., 4th ser., vol. 6, p. 181, 1898); analysis VI, by L. P. Kinnicutt.

In the quantitative classification the three types are related as follows:

Petrographic relations of igneous rocks analyzed.

Rock.	Class.	Order.	Rang.	Subrang.
Microgranite	I. Persalane	3. Columbare 4. Britannare	1. Liparase	3. Liparose. (Sodipotassic.)
Graphic microgranite	I. Persalane	3. Columbare 4. Britannare	2. Alsbachase.	4. Alsbachose. (Dosodic.)
Blue-quartz porphyry	I. Persalane	3. Columbare 4. Britannare	1. Alaskase	4. (Dosodic.)
Riebeckite porphyry	II. Dosalane	4. Austrare	1. Pantellerase	4. Pantellerose.

It is probable that the analysis of the microgranite is slightly incorrect, as all the slides cut from this rock show a little magnetite. They come near the line between orders 3 and 4, but within order 3.

The slight increase in the calcium just throws the graphic microgranite into the second rang. The considerable increment of sodium the rock receives in passing from microgranite to porphyry is indicated by the subrangs. The above table shows the general order of the appearance of the rocks, the blue-quartz porphyry being the later. We may assume that the similar blue-quartz porphyry in the Cumberland area, which contains soda orthoclase and a little riebeckite, may carry even more sodium.

All these types come in the category of alkali granite, as does also the Milford granite. Of the four series present in the Essex County basin only the granito-dioritic and the related series of dike rocks occur in the region here considered. The foyaitic series and its dike rocks are absent, although the riebeckite porphyry has a foyaitic aspect.[a]

RÉSUMÉ SHOWING RELATION OF THE PORPHYRIES TO ONE ANOTHER AND TO THE CARBONIFEROUS SEDIMENTARY ROCKS.

We may imagine the complex of intrusive rocks here described to have intruded into the Cambrian schists, in an early stage of the Carboniferous period, as a laccolithic mass which, before solidifying, was slightly differentiated along its northern side into a more basic border, represented by the black gneiss of Bald Hill, which occurs along the only portion of the boundary that is exposed.

A broad, continuous band of the granite adjoins this narrow border on the south. The rock of this band seems to have solidified mainly a little later than that of the border, which it seems to underlie, and to have formed the nucleus of the stock. Still farther south is the extensive microgranite and graphic microgranite complex, which seems also to be a little older than the granite porphyry and to have mantled over it around the southern side, as the dark granite did around the northern. Indeed, a little of the microgranite is found on the north side where the dark gneiss joins the granite porphyry, and this occurrence increases the probability that the two former rocks are portions of a common mantle over the granite.

Only a part of the stock is exposed and of this the outcrops at critical points are so poor that no very clear evidence could be gathered concerning the exact relations of the three rock types, either as to time or superposition. They seem to blend by sharp transitions into one another and to be three very similar facies of a common stock, since they have a microgranitic groundmass and many other peculiarities in common and are closely allied chemically.

In the interesting central area the graphic microgranite is probably a variant of the granular microgranite formed somewhat below the present surface, and since the chemical constitution of the two is so nearly the same their difference of texture was caused by some small but unknown difference of physical conditions. This graphic microgranite has been brecciated and has been penetrated by a portion of the granite porphyry, and a certain stratiform structure has been given to the whole mass of the resulting breccia—a structure showing northerly dips, as represented upon the map.

The breccia contains more graphic microgranite in its southern por-

[a] Washington, H. S., The petrographical province of Essex County, Mass.: Jour. Geol., vol. 7, 1899, p. 469.

tion and more granite porphyry in its northern portion where it adjoins the granitoid rock. The breccia preserves the record of several stages: (1) The formation of a fine massive graphic microgranite, (2) a partial breaking up of the rock, by which it was involved in a second microgranite or micrographic granite, which shows flow structure by distinct banding, and (3) the blending of great angular pieces of these two very fine-grained rocks and of granite with many small and very small fragments of the same rocks which seem (4) to have been carried along and to have been cemented by a small quantity of the granite porphyry. There is (5) indication of a blending of the breccia upward with the ordinary Carboniferous conglomerate. The fragments have been transported very slightly or not at all and still fit together and at places where the porphyry could not penetrate are cemented by films of biotite and magnetite brought in by heated solutions. This interstitial porphyry is much more irregular in grain than the normal porphyry outside, and is somewhat crushed and filled with trains of magnetite grains. There is no scoriaceous structure which would indicate a surface flow, and the rock was probably a somewhat deep-seated deposit of the intruding porphyry. The great quantity of angular and fresh fragments of the microgranite and granite porphyry that occur in the adjacent Carboniferous conglomerate suggest the idea that they are the result of an eruption of tuffaçeous material rather than a result of slow erosion of the surface of the laccolith. The identity, under the microscope, of material taken from the fresh rock in the microgranite ledges and from small fragments in the Carboniferous conglomerate serves to confirm this suggestion, as does the fact that the later metamorphism of this conglomerate did not form aluminous silicates (chiastolite, fibrolite, andalusite), the common products of metamorphism of argillaceous Carboniferous rocks farther north, but formed sericite, biotite, and chloritoid; that is, if the igneous material of the breccia had been obtained by erosion it would have been largely altered and kaolinized and would have been largely metamorphosed into the aluminous silicates mentioned above, but as it consisted of fresh fragments of the microgranite it altered into the alkaline silicates named. The presence of chloritoid would be due to the abundant presence of iron, indicated by the abundance of secondary magnetite.

Under the postulates of piezocrystallization the presence of these minerals may be taken to indicate a somewhat deep-seated crystallization, though without invalidating the former conclusion. The microgranite mass and the dark border bed seem to have been first solidified against superincumbent rocks, which favored a slight basic differentiation on the north and the development of a fine-grained facies on the south. The granite solidified a little later, and lower. Later microgranite dikes penetrated the granite and the dark border granite.

An explosive eruption seems to have blown off the capping of microgranite and graphic microgranite, furnishing the great mass of microgranite and porphyritic granite fragments which find place in the adjacent Carboniferous conglomerate, and permitting the blending of the two seen at the schoolhouse west of Spencer Hill. That portion of the magma which ran in this conduit consolidated as a porphyry, because its quartz and feldspar phenocrysts had already solidified below, and on the sudden transference of the mass to a higher level the remainder solidified as an exceptionally fine-grained groundmass. The one part of this porphyry cemented shattered fragments of the graphic microgranite; the other filled the remainder of the chimney forming the central mass of porphyry.

The existence of the Wamsutta volcanoes of this age in the adjacent territory studied by Mr. Woodworth and the conclusion of Mr. Washington that the Essex County complex is laccolithic and not deep magmatic favor the conclusion that the consolidation of the mass may have been so superficial that a last explosion may have broken through the roof and supplied the fragmental material for the conglomerate.

The next step would be the further spreading of the Carboniferous conglomerates over the area, and the wide distribution of fragments of the granites and microgranites as bowlders in these conglomerates. Then came a metamorphism of the latter, changing their paste into a coarse mucovite schist, developing therein garnet, biotite, and chloritoid, and carrying iron in considerable quantity into the rock, where it is developed as magnetite in the paste and penetrated the pebbles of the microgranite and the feldspar of the microclinite, producing elaborate dendritic growths of the black oxide. In this connection we may recall the fact that scales of biotite are scattered through the inner portions of the fragments of graphic microgranite and are absent from their borders, where they come in contact with the quartz-porphyry, the condition indicating that they were resorbed by the caustic effect of the inclosing rock.

Continued study of the problem, however, has weakened each of the lines of evidence relied upon to prove the early Carboniferous age of the East Greenwich group:

(1) Professor Jaggar has collected much evidence to show that the Quincy hornblende granite differs in age from the biotite granite of the Boston basin, with which the East Greenwich group is more nearly allied.

(2) The recent discussions by Barrell,[a] Mansfield,[b] and others on the continental transport of unaltered feldspathic material in semiarid regions suggest another explanation of the fresh granite pebbles in the conglomerate.

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[a] Barrell, J., Studies for students: Jour. Geol., vol. 14, pp. 316–356, 430–457, 524–568, 1906.

[b] G. R. Mansfield, Roxbury conglomerate: Bull. Mus. Comp. Geol., vol. 49, 1906, p. 91.

(3) A further study of the schoolhouse locality mentioned above has shown that, while the transition from the breccia to the conglomerate seems complete, a break may be concealed by the considerable metamorphic change.

(4) The succession of events becomes simpler if we assume that the porphyries and micrograpites of the series formed the surface of a rather thinly covered batholith, which was just exposed by erosion in early Carboniferous time.

Gould Island, east of Conanicut, would seem, from Mr. Foerste's description, to be made up of a graphic granite breccia like the one here described.[a]

IGNEOUS ROCKS OF POST-CARBONIFEROUS AGE.

Olivine-diabase porphyry.—In a quarry by the roadside, 1 mile southwest of Olney Pond, near the south line of Lincoln, is a dike 1½ to 2 feet wide, running N. 50° E. and dipping 60° NE. It indurates the granite, and is more compact at its border. It is a fine-grained, fresh, black trap, minutely porphyritic, with feldspar needles and olivine crystals, and contains quartz grains, probably derived from the granite. The large feldspars are labradorite, with extinction angles of 23½° on (010). The smaller feldspars are anorthite with maximum extinction 34° in the albite zone. The olivine phenocrysts are half serpentinized; otherwise the rock is very fresh. Granular pyroxene and feathery magnetite make the ground in the coarser center of the dike; an aphanitic ground of glass full of black oxide makes the ground on the border and incloses porphyritic labradorite and olivine exactly like those in the center of the dike, showing that these had floated there after first consolidation elsewhere.

In the deep limestone quarry north of the road and nearest Lime Rock are two dikes, 2 and 2½ feet thick, which run N. 50° W., and dip 60° NE. The trap dikes are echeloned by several slight displacements, while the limestone that incloses them, as noted by Woodworth, shows no different texture here to indicate the motion that has taken place. Many contact pieces obtained directly underneath the limekilns show no visible influence of the trap on the limestone, and in the slide the only endomorphic effect was a darkening of the ground of the trap for one-eighth inch. These dikes branch from a single one at the head of the quarry. The trap is the same jet-black rock as the trap at Lincoln described above, not quite so coarse at the center, but quite the same at the border. The large feldspars are labradorite, beautifully twinned on the albite and pericline laws. The olivine shows peculiar alteration. The olivine network does not appear. The few fissures and the surface are black with secondary magnetite. The whole mass is changed into a fibrous

[a] Geology of the Narragansett basin: Mon. U. S. Geol. Survey, vol. 33, 1899, p. 272.

mass of talc needles radiating from many centers. At some places a later agent has changed the central portion of the olivines into an oil-green serpentine. At others the large feldspars, though generally quite fresh, are changed within sharply defined fields, or within segments of a single crystal, into a fibrous mass of a white micaceous mineral.

A similar dike, or vein, 1½ inches wide, has just been exposed beneath the buildings at the quarry. It is fused with the limestone, and portions taken from its black pitchstonelike mass, at places where it is penetrated by the pure white limestone, form beautiful cabinet specimens. This dike has produced no metamorphic effect on the limestone.

Doctor Jackson[a] maps another dike east of the river opposite the Dexter quarry.

Porphyritic diabase.—One mile southeast of Spencer Hill, in Warwick, a rather coarse and exceptionally fresh diabase was found, which is of exactly the same type as the Holyoke trap. It has a porphyritic aspect, due to the presence of small groups of stout plagioclase plates of first consolidation, which are near bytownite in composition. The augite is amethystine, often twinned and mostly xenomorphic. The rock contains rather large blebs of brightly polarizing devitrified glass, wherein an original perlitic structure is now marked by lines of black ore grains.

Basic eruptive rocks are rare in the region, especially in the Carboniferous area. Professor Woodworth maps a series of altered diabase dikes that extend from North Attleboro by Lanesville to Arnolds Mill, in the "Wamsutta group" of the Carboniferous.[b]

Mr. Foerste mentions two minette dikes that cut the Carboniferous shales in the southern half of Conanicut Island.[c] The authors found dikes of coarse gabbroid diabase in Woonsocket.

[a] Report on the Geological and Agricultural Survey of the State of Rhode Island, 1840.
[b] Mon. U. S. Geol. Survey, vol. 33, 1899, p. 152.
[c] Idem, p. 232.

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CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 311.]

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CHARLES D. WALCOTT, DIRECTOR

THE INTERACTION BETWEEN MINERALS AND WATER SOLUTIONS

WITH

SPECIAL REFERENCE TO GEOLOGIC PHENOMENA

BY

EUGENE C. SULLIVAN

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THE INTERACTION BETWEEN MINERALS AND WATER SOLUTIONS, WITH SPECIAL REFERENCE TO GEOLOGIC PHENOMENA.

By Eugene C. Sullivan.

INTRODUCTION.

The work described in the following pages was undertaken in the chemical laboratory of the United States Geological Survey, in an attempt to apply chemical methods to the investigation of geologic processes and especially of the secondary deposition of ores.

The concentration of metals by water solutions in deposits of sufficient magnitude to constitute ore bodies involves two processes—the taking up of the metal from its original seat, and its redeposition at a point favorable for accumulation. As to the first process, water, and especially water solutions, must be assumed to attack and dissolve to a greater or less extent all minerals with which they come into contact. Various causes will lessen or increase the extent of this action in the case of any particular mineral; but in every instance, no matter how infinitesimal the quantity dissolved as measured by ordinary laboratory standards, the solubility is capable, through long periods of time, of producing important geologic effects. Tho process of solution therefore involves no special difficulties.

Chief interest will center on the deposition, in one spot, of a mass of metal gathered by the solvent waters from over a wide range of country. It is important both from a scientific and from an economic point of view to know what agent determines that the metal from an immense volume of solution, which has passed undisturbed through a section of rock very large in comparison with that in which it is finally concentrated, shall be deposited in a certain limited area, to constitute a valuable body of ore. Physical conditions, such as comminution of the rock, stagnation of the carrying waters, local variations in temperature, or mingling of solutions, may have been important factors. They become important, however, chiefly in so far as they accelerate or otherwise modify chemical reactions, and a thorough knowledge of the reactions possible under natural conditions seems to be a necessary foundation for study along this line.

With this in view some of the changes that take place at ordinary temperature when water solutions are brought into contact with rock-forming minerals have been examined.

The result has been, in a word, to make it apparent that chemical reaction between silicates and salt solutions is a very general phenomenon, taking place to a decided extent immediately upon contact, and that the outcome is mainly an exchange of bases in chemically equivalent quantities between solid and solution; the metal of the dissolved salt is precipitated and an equivalent quantity of silicate is decomposed and its bases enter the solution. Salt solutions as decomposing agents are much more active than pure water and are comparable with acids in this respect.

A review, as brief as possible, has been made of our present knowledge of the reactions between salt solutions and silicates in so far as it seems likely to have bearing on geologic work. The fact that no connected survey of this field exists and that the literature is scattered, most of the early papers having appeared in agricultural journals not readily accessible as a rule to the geologist and mineralogist, perhaps justifies the expectation that such an outline will prove useful. By no means all of the published papers bearing on the subject are mentioned in the text; the treatment has been confined to the briefest statement consistent with the development of the facts.[a]

The work described in the present paper is but an incomplete outline of a part of the field. Important work to be done suggests itself at once.

The investigation should be extended both as to salt solutions and as to minerals.

The character of the precipitates obtained by interaction between salt solutions and minerals should be investigated by grinding the minerals in the solutions, which should give the end products in a comparatively short time by abrading the surfaces already acted upon and continually exposing fresh material to the solution.

The action of minerals on mixtures of salts in solution, and thus possible natural processes of separation, should be studied.

Where separation of metals has taken place, caused apparently by difference in character of wall rock, the opportunity and desirability of laboratory investigation are obvious.

Equilibrium conditions are still to be worked out. These are of great interest, both scientifically and practically, as showing the possibility of decomposition or the direction of decomposition of a mineral as dependent on the make-up of the solution with which it is in contact.

[a] References to the literature on this and related subjects are assembled in Cameron, F. K., and Bell, J. M., The mineral constituents of the soil solution: U. S. Dept. Agr., Bull. Bur. Soils No. 30, 1905.

It can not be doubted that the collection of definite comparative data along these lines will also throw light on questions of mineral constitution.

The possible practical effects of diffusion through wall rock, etc., should be ascertained experimentally.

OUTLINE OF EARLIER WORK.

FILTRATION AND DIFFUSION.

That water is improved for drinking purposes by filtration through sand was known as early as the time of Aristotle.[a]

Francis Bacon[b] writes of a method of obtaining fresh water practiced on the coast of Barbary: "Digge a hole on the seashore somewhat above high-water mark and as deep as low-water mark, which when the tide cometh will be filled with water fresh and potable." He also remembers "to have read that trial hath been made of salt water passed through earth through ten vessels, one witnin another, and yet it hath not lost its saltness as to become potable," but when "drayned through twenty vessels hath become fresh."

Dr. Stephen Hales[c] mentions, on the authority of Boyle Godfrey, that "sea water being filtered through stone cisterns, the first pint that runs through will be like pure water, having no taste of the salt, but the next pint will be as salt as usual."

Berzelius filtered solutions of common salt through sand and found the first portions of the filtrate fresh. Matteucci[d] obtained similar results with other salts.

Although such phenomena are attributable to adsorption—an accumulation of dissolved substance on the contact surface liquid-solid, the filtering medium with its large surface affording favorable conditions for such an effect—the possibility is to be considered that we are dealing with the result of the different diffusivity of the constituents of a solution. Each substance has its own velocity of diffusion, and where free passage is interfered with, as in the filtration of a water solution, the water, traveling more rapidly than the salts, may come through first.

Krawkow,[e] on comparing pure water and solutions side by side, found that the water moved more rapidly through a soil. Briggs obtained similar results, which he attributed to the greater viscosity of the solutions.[f]

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[a] Sachsze, Agriculturchemie, p. 146.

[b] In Sylva Sylvarum, quoted by Way, Jour. Roy. Agr. Soc., vol. 11, 1850, p. 316.

[c] In a paper read before the Royal Society in 1739 on "Some Attempts to make Sea-Water Wholesome," cited by Way.

[d] Sur les phénomènes physiques des corps vivants, Paris, 1847, p. 29, cited by Way.

[e] Jour. für Landwirtschaft, vol. 48, 1900, p. 209.

[f] U. S. Dept. Agr., Bull. Bur. Soils No. 19, 1902.

King,[a] on filtering very dilute soil solutions (containing carbonates, sulphates, nitrates, and phosphates) through a porcelain filter, observed an increase in the concentration of the unfiltered portion. The matter was followed up by Briggs, who found in the case of N/1000 solutions of potassium sulphate, sodium bicarbonate, and potassium nitrate a decrease in the concentration of the filtrate and an increase, amounting to 2 or 3 per cent, in the concentration of that part of the unfiltered liquid nearest the filter. Sodium carbonate solution (N/1000) suffered the greatest loss (15 per cent) on filtering. "This would follow from the tube behaving as an imperfect semipermeable membrane, allowing the water to pass through the filter walls more readily than the dissolved salt."

When the material is somewhat readily penetrable but slight separation will be effected in this way. With relatively impervious material, however, important separation of the constituents of a solution is possible, as in dialysis of a salt solution through an animal membrane, leaving behind colloid matter, the velocity of diffusion of which is practically nil as compared with that of electrolytes. Still less pervious are the so-called semipermeable membranes, such as a film of precipitated cupric ferrocyanide, which permit the solvent to pass, but not the dissolved salt.

G. F. Becker[b] suggested the possibility of natural concentration of metals by dialysis, the confining rock of an underground water channel acting as a septum.

Kohler[c] describes experiments on the filtration of salt solutions through kaolin. Cupric sulphate and lead nitrate solutions, after passing through a layer of washed kaolin (some 20 cm^3 of dilute solution with 25 grams kaolin in an ordinary glass funnel), contained but very little of the metals. Sodium chloride, sodium sulphate, and magnesium sulphate solutions under similar treatment took on acid reaction. Kohler attributes these results to adsorption—a selective concentration of dissolved substance, here the bases of the salts, on the surface of a solid—and discusses the possibility that concentration of metals by this means has led to the formation of ore bodies.

The writer, on filtering magnesium chloride and sodium chloride solutions through kaolin, as described by Kohler, found the filtrate faintly but distinctly acid to litmus. With sodium chloride the first 4 or 5 cubic centimeters of filtrate had about the same degree of acidity as a solution 0.001 normal. Such acidity seems sufficiently accounted for by the exchange of the magnesium and sodium of these salts in part for the iron and aluminum of the kaolin, the salts of the latter metals undergoing extensive hydrolysis in dilute

[a] Briggs, U. S. Dept. Agr., Bull. Bur. Soils No. 19, 1902, p. 36.
[b] Mineral Resources U. S. for 1892, U. S. Geol. Survey, p. 156.
[c] Zeitschr. prakt. Geol., vol. 11, 1903, p. 49.

solution. The acidity observed is of the same order of magnitude as the quantity of trivalent bases found in dilute copper sulphate solution after contact with kaolin.

The acidity of a salt solution after filtration through a substance, such as kaolin, through which the liquid diffuses but slowly, may be due to some extent to the greater velocity of diffusion of the acid constituent of the salt, which is present owing to hydrolysis—the splitting up of a salt into its acid and base by the action of water:

$$CuSO_4 + 2H_2O = Cu(OH)_2 + H_2SO_4.$$
$$Fe_2(SO_4)_3 + 6H_2O = 2Fe(OH)_3 + 3H_2SO_4.$$

In water solutions of salts of heavy metals the base is present, to a greater or less extent, in the colloidal condition, and colloids are marked by their very slow rate of diffusion.

P. Rohland[a] states that a certain clay was permeable to crystalloid solutes, such as sodium chloride, barium chloride, cupric sulphate, potassium dichromate, etc., while it was impermeable to colloids, such as ferric hydroxide, silicic acid, and dissolved starch.

Spring[b] observed the separation of acid and base by diffusion and the consequent deposition of the metal hydroxide in media similar in character to a suspension of clay in water. The suspended material—in one case, gum mastic (an emulsion of the resin in water, a milky liquid obtained by pouring an alcoholic solution of mastic into water); in another, silica—was superposed in a column 15 cm. in height on a concentrated solution of the salt and diffusion allowed to take place. Coagulation or sedimentation of the solid was caused immediately and the particles descended to the point at which their density and that of the solution were the same. The height to which flocculation extended was not the same for different salts. Above the cupric sulphate solution the layer in which flocculation took place reached a height of 11.5 cm. The copper had diffused upward not more than 7 cm., as shown by the absence of color and by the ferrocyanide test in a portion removed by means of a pipette. Sulphuric acid was, however, present in the higher 4.5 cm. Other salts—aluminum chloride, ferric chloride, alum, magnesium chloride, zinc chloride—gave similar results. Above the layer of salts in each case free acid was found.

The flocculent deposit above the cupric sulphate solution, removed with a pipette and washed on a filter, was of yellow-green color and contained cupric hydroxide. Aluminum, iron, zinc, and magnesium were shown to be present in mastic precipitated by means of their salts in the same manner.

If, however, the turbid mastic was shaken with cupric sulphate or aluminum chloride solution, the flocks of mastic which formed did not

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[a] Zeitschr. Elektrochem., vol. 11, 1905, pp. 455-456.
[b] Bull. Acad. roy. Belgique, vol. 70, 1900, p. 496.

retain copper or aluminum. Washed on a filter and tested, they gave no reactions for those metals.

"The decomposition of the salts depends then only on the condition that diffusion intervenes and that, in any case, agitation does not bring base and acid into contact." "The mastic suspension apparently performs the same office as a permeable wall in the sense that it retains the molecules of hydroxide in order to precipitate with them, while it allows the molecules of acid to pass more freely."

The same results were obtained when silica was used as the suspended material instead of mastic.

Bruni and Vanzetti[a] have shown that in the diffusion of cupric sulphate solution through gelatine the sulphuric acid separated by hydrolysis travels appreciably faster than the base. The blue solution is preceded by a colorless layer containing acid. With ferric chloride similar results were observed.

A further cause to which may be attributed acidity of a solution after contact with a hydrated silicate is double decomposition between the salt and silicic acid, or alumino-silicic acid, the hydrogen of the latter replacing in solution the metal of the salt. Such action takes place readily enough in alkaline solution: $H_2SiO_3 + 2KOH = K_2SiO_3 + 2H_2O$. It is slight if at all measurable with neutral salts.

CHEMICAL REACTION.

That solutions may be deprived in part of their dissolved substances by sandy material has therefore long been well known. The fact that clays, soils, etc., enter into chemical exchange with solutions, giving off some things and taking up others, appears to have first been specifically recognized by H. S. Thompson, an Englishman, who published his observations in 1850.[b] Thompson found that ammonium sulphate solution filtered through soil or clay exchanged its ammonium for calcium. The filtrate contained chiefly calcium sulphate. Similar experiments with ammonium carbonate also showed a reaction between the dissolved substance and the solid.

The matter was taken up and studied in detail by J. Thomas Way, chemist to the Royal Agricultural Society, whose work is described in the journal of the society for 1850 and following years.[c] Way found that when an ammonia solution passed through soil or clay the percolating liquid contained neither ammonia nor ammonium salts. His first experiment was carried out in a tube 20 inches long and of three-fourths inch internal diameter, which when about two-thirds filled contained 2,800 grains (180 grams) of soil. The soil used had been dried in air. A 1.5 per cent solution of ammonia was used, and the

[a] Atti Reale Acad. Lincei [5] 15 II, December, 1906, pp. 705-715.
[b] Jour. Royal Agr. Soc., vol. 11, 1850, pp. 68-74.
[c] Jour. Royal Agr. Soc., vol. 11, 1850, pp. 313-379; vol. 13, 1852, pp. 123-143; vol. 15, 1854, p. 491.

first portions took from one and a half to two hours to percolate through the column. When one ounce (30 cm.³) had passed, it was tested and found to contain no trace of ammonia or ammonium salts. Quantitative experiments showed that the soil had taken up ammonia equal in amount to about three-tenths of 1 per cent of its own weight. The result was the same on forcing the solution through by pressure, so that contact lasted but a few seconds.

Solutions of salts, such as the nitrates, chlorides, and sulphates of ammonium, potassium, sodium, and magnesium, filtered through soil gave up the respective bases entirely and received in exchange calcium from the soil. In the case of ammonium chloride it was shown that the chlorine content of the solution was not affected by contact with the soil. Filtration through a white pottery clay led to similar results, sodium being in this instance the substituting base; again the concentration of the chlorine was unchanged.

Way had no difficulty in proving that the active ingredient of the soil in absorption of bases was its clay. Owing to the relatively small proportion of base taken up by clay (a few tenths of 1 per cent of its weight), he concluded that the action was due, not to the clay as a whole, but to some constituent present in small quantity. Evidence tending to show that this constituent was a hydrated alumino-silicate of alkali or alkaline earth he obtained by demonstrating that artificial alumino-silicates of sodium, potassium, calcium, magnesium, and ammonium were capable of exchanging bases with salt solutions exactly as the soils had done. It does not, however, follow that the soil contains zeolitic silicates which are responsible for such action, as has been sometimes assumed.[a] Apparently any silicate, including the feldspars, is capable of entering into these reactions.

Sodium alumino-silicate was prepared by mixing sodium silicate and sodium aluminate solutions. The precipitate washed with water and dried was a white powder practically insoluble in water and containing some 18 per cent of soda. The other compounds were similarly prepared or were obtained from this one by substitution—the ammonium compound, for instance, by digesting with ammonium chloride solution, which removed sodium and formed an ammonium alumino-silicate.

Way clearly recognizes the nature of the phenomena with which he is dealing as the chemical replacement of one base by another. He says, for instance:[b] "It will be abundantly evident as we proceed that the absorptive power of soils is something entirely different from a surface attraction." Again, "the quantity of lime acquired by the solution corresponded exactly to that of the ammonia removed from it—the action was therefore a true chemical decomposition."[c]

[a] This point has been emphasized by Merrill, G. P., Rocks, Rock-Weathering, and Soils, New York, 1906, pp. 362-365.

[b] Loc. cit., 1850.

[c] Loc. cit., 1852.

Way investigated also the influence of concentration and of temperature. The amount of exchange between solution and solid was found to increase with increasing concentration of the solution used, and to increase also, although but slightly, with rising temperature.

He observed that absorption was greater from alkaline than from neutral solution, and that absorption of free alkali (potassium hydroxide) was increased by previous boiling of the clay with hydrochloric acid. The cause of the latter phenomenon, the decomposition of silicates with resulting formation of colloid silica or silicic acids, he did not recognize.

The relative ease with which the bases enter into these substitution reactions appears to depend somewhat upon the conditions of experimentation. Way makes the statement that sodium, potassium, calcium, magnesium, and ammonium will each be dislodged from its alumino-silicate by a salt of any of those following it in the order given.[a] Potassium should be with ammonium as one of the bases least readily replaced from silicates by substitution, not, as Way has it, at the other end of the series. He erroneously states that these changes are not reversible.

The capacity of the feldspars to enter into these reactions was not recognized by Way. He says:[b] "It is only in the state of hydrates that the double silicates possess the property in question; this is the reason why feldspar and albite substances, of the same composition in all other respects as the artificial silicates, are devoid of the power of absorbing ammonia."

Important to our present purpose, as illustrating the practical effect of silicates on organic matter, is the same author's description of the action of clay on barnyard liquors. These filtered through clay lost their color, odor, and taste. Sand was comparatively inefficient in this respect, although, as shown by Angus Smith,[c] it had some oxidizing action, changing the nitrogen of organic compounds into nitrate.

Eichhorn[d] studied the reactions between salt solutions and individual natural minerals, such as chabasite, $(Ca,Na_2)Al_2(SiO_3)_4,6H_2O$, and natrolite, $Na_2Al_2Si_3O_{10},2H_2O$. The following table shows the extent of substitution obtained with dilute solutions of the salts named. Four grams chabasite, finely powdered, 4 grams salt, 400 cm^3 water were taken; contact was for ten days, presumably at room temperature:

Composition of chabasite as affected by salt solutions.

	Before action of salts.	After action of NaCl.	After action of NH_4Cl.
	Per cent.	*Per cent.*	*Per cent.*
CaO	10.37	6.65	4.15
Na_2O	0.42	5.40	$(NH_4)_2O$ 6.94

[a] Loc. cit., p. 132. [b] Loc. cit., p. 135. [c] Cited by Way, loc. cit. [d] Pogg. Ann., vol. 105, 1858, p. 126.

Exchange has taken place in approximately equivalent quantities. Sodium carbonate and ammonium carbonate with chabasite gave similar results. The ammonium substitution product gave off no ammonia on heating to 100°, yet in contact at ordinary temperature with a solution containing chloride of calcium, sodium, potassium, or magnesium the ammonium was removed and the other base substituted. Eichhorn showed that these substitutions are reversible. After treatment with sodium chloride the altered chabasite, for instance, gave up sodium to calcium chloride solution. "The bases," he says, "appear to be mutually replaceable." He recognized the fact that some substitutions took place more readily than others, and as a measure of such ease of substitution he ascertained the time in which the salts of various bases drew calcium into solution from chabasite. The order found was as follows, those first in the list extracting a detectable amount of calcium most rapidly: Potassium, sodium, lithium, barium chlorides; cadmium nitrate; zinc, strontium, magnesium chlorides. This order, he remarks, may be modified by varying concentration of the salts.

Henneberg and Stohmann[a] in 1858 described experiments confirming Way's results. They found that ammonium or potassium hydroxide, carbonate, nitrate, chloride, or sulphate in contact with soils of the widest variation in character gave up ammonium or potassium to form insoluble compounds. In the case of the nitrate, chloride, and sulphate—salts almost neutral in water—the acid content of the solution remained unchanged, the acid which had been combined with the absorbed ammonium or potassium reappearing in combination with calcium or magnesium. From solutions of phosphates, silicates, etc.—salts alkaline in water—the acid radical also was in part precipitated. Sodium and magnesium salts were found to behave like salts of ammonium and potassium. The following data are typical of those obtained in these experiments. The figures show the number of grams of ammonia (NH_3) absorbed by 100 grams of soil from 200 cm³ of solutions of the concentrations indicated.

Ammonia absorbed by soil from salts of ammonium.

	0.05 gram equivalent per liter (0.17 g. NH_3 in 200 cm³).	0.1 gram equivalent per liter (0.34 g. NH_3 in 200 cm³).	0.2 gram equivalent per liter (0.68 g. NH_3 in 200 cm³).	0.5 gram equivalent per liter (1.7 g. NH_3 in 200 cm³).
NH_4OH	0.058	0.095	0.149	.....
NH_4Cl	0.0545	0.071	0.107	0.118
NH_4NO_3	0.054	0.080	0.106	[0.170?]
$(NH_4)_2SO_4$	0.057	0.086	0.118	.....
$(NH_4)_2HPO_4$	.....	0.141	0.206	.....

The amount of ammonium taken from solution is about the same whether it is present as chloride, nitrate, or sulphate—salts which in water solution are almost neutral to indicators. With ammonium

[a] Ann. Chem., vol. 107, 1858, p. 152; more fully, Jour. Landw., vol. 3, 1859, p. 25.

hydroxide and ammonium phosphate—alkaline in water solution—the quantity absorbed is somewhat greater.

Henneberg and Stohmann found also that the greater the quantity of solution taken with a fixed quantity of soil the greater was the absorption. In certain cases, for instance, doubling the amount of solution increased the amount of absorption one-fifth. The time of contact, as Way had already shown, was of little influence. Absorption was not greater in one hundred and sixty-eight hours than in four.

The authors compare the quantities of ammonium precipitated and calcium dissolved, but remain in doubt as to whether substitution in chemically equivalent amounts has taken place, possibly because they fail to determine the bases other than calcium taken from the soil by the solutions.

Peters[a] investigated the action of soils on solutions of potassium salts, making complete analyses of the solutions after contact with the soils. The tables following indicate the general nature of the results. The data in the first table, obtained in four experiments carried out under conditions supposed to be identical, with 250 cm^3 potassium chloride solution (N/20, equivalent to 2.36 grams K_2O per liter) and 100 grams soil, allow some estimate of the accuracy attained. The lack of agreement is undoubtedly due in part to actual nonuniformity in the experimental results and in part to the errors of analysis.

Action of soils on potassium chloride solution.

K absorbed equivalent to grams K_2O.	Found in 250 cm^3 solution—			
	CaO.	MgO.	K_2O.	Na_2O.
0.2130	0.1176	0.0032	0.3758	0.0463
0.2015	0.1176	0.0048	0.3873	0.0439
0.1976	0.1120	0.0048	0.3912	0.0370
0.1841	0.1064	0.0050	0.4047	0.0450

As showing the influence of the anion and of concentration the following data derived from the contact of 100 grams soil with 250 cm^3 solution may be quoted from Peters:

Influence of anion and of concentration in action of soils on solutions of potassium salts.

Salt.	Concentration.	K, expressed as grams K_2O.	
		Originally in 250 cm^3.	Absorbed from 250 cm^3.
KCl	N/80	0.1472	0.0988
KCl	N/40	0.2944	0.1381
KCl	N/20	0.5888	0.1990
KCl	N/10	1.1776	0.3124
KCl	N/5	2.3552	0.4503
K_2SO_4	N/20	0.5888	0.2089
K_2SO_4	N/10	1.1776	0.3362
KNO_3	N/20	0.5888	0.2516
K_2CO_3	N/20	0.5888	0.2792
K_2CO_3	N/10	1.1776	0.4705
KOH	N/20	0.5888	0.4018
KOH	N/10	1.1776	0.7347

[a] Landw. Vers.-Stat., vol. 2, 1860, p. 113.

Here again absorption from the salts in neutral solution is roughly the same whatever the form of combination, while from alkaline solution the absorption is greater. The slow increase in absorption as concentration rises is also exemplified. Peters found that the chloride and sulphate ions were not absorbed, while the phosphate ion was. The following order of absorption is given for the bases, that absorbed in greatest quantity being placed first: Potassium, ammonium, sodium, magnesium, calcium.

The bases dissolved from the soil were replaced in very nearly equivalent quantity by the absorbed base. From "bases dissolved" has been subtracted that quantity which is dissolved from the soil by water alone.

Comparison of bases dissolved with potassium absorbed from chloride solution.

Original concentration	Bases dissolved, equivalent to grams K_2O.	K absorbed, equivalent to grams K_2O.
N/80	0.0891	0.1012
N/40	0.1241	0.1381
N/20	0.2061	0.1990
N/10	0.3138	0.3124
N/5	0.4545	0.4503

The results of experiments by Peters on the absorption of potassium chloride from solution by wood charcoal are also of importance. The charcoal was washed with alcohol and ether and dilute nitric acid and carefully dried. The quantities are stated in grams.

Reaction between wood charcoal and potassium chloride solution.

KCl.	Found in solution.			Absorbed.	
	CaO.	K_2O.	Cl.	K_2O.	Cl.
N/20	0.0128	0.5410	0.4254	0.0478	0.0179
N/10	0.0280	....	....	0.0795	0.0329

A certain amount of the entire salt has apparently been absorbed. The potassium absorbed in excess of that equivalent to the chlorine absorbed has been replaced in solution by an equivalent quantity of calcium.

Although recognizing that "for the absorption of bases from salts a chemical exchange with the constituents of the soil is necessary," Peters clings to the idea of physical retention; "this [chemical exchange] is made possible by the help of the great 'predisposing' affinity exerted by the soil on the bases." "The absorption is conditioned by surface attraction which the molecules of the soil exert."

The generally accepted view thus expressed by Peters was that taught by Justus Liebig, the dominant figure in agricultural chemistry

in the middle of the nineteenth century, and, indeed, the creator of that branch of science. Soil was known, even before Way's time, to have the power of taking up and holding gaseous ammonia, and this was ascribed by Liebig to mechanical attraction exerted by the soil particles and manifested on their surface.

Rautenberg[a] in 1862 carried on a series of careful experiments to determine what constituent of the soil was responsible for its absorptive properties, and in the end adopted Way's view that the capacity for absorption depended on certain hydrous silicates. His work was confined to solutions of ammonium compounds. He concludes that in general the bases dissolved are equivalent to the ammonium absorbed, but still recognizes mechanical influences in the absorption.

Küllenberg[b] three years later published an exhaustive comparison of the effects of various salt solutions through a range of concentrations on a single soil. It will be worth while to reproduce his results here, as they constitute the most systematic investigation of the matter that has been undertaken. An attempt to plot the results as curves reveals occasional inaccuracies of considerable magnitude, but on the whole the data furnish a probably correct outline of existing relationships.

It may be observed again that the base enters into reaction to approximately the same extent whether it is combined as sulphate, chloride, or nitrate. So far as there is a difference, more of the base is removed from sulphate solution than from the others. On comparing chemically equivalent quantities it is seen that ammonium is taken from solution in greatest degree, followed in order by potassium, magnesium, sodium, and calcium. As to the bases dissolved from the soil, Küllenberg's conclusion is that "for the absorbed base nearly equivalent quantities of other bases, already present in the soil, have been carried over into the solution."

Eighteen experiments with sulphates showed no absorption of SO_4. Twenty with chlorides showed no absorption of Cl. The significance of this is of course somewhat lessened by the fact that the soil contains both sulphate and chloride.

The composition of the soil is shown on the next page.

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[a] Jour. für Landw., vol. 7. 1862, pp. 405–554; also vol. 7, 1862, pp. 49-66.

[b] Mitteil. d. landw. Centralvereins für Schlesien, Heft 15, p. 83; also Jahrb. Fortschr. Agr. Chem., vol. 8, 1865, p. 15.

Composition of soil used in Küllenberg's experiments.

Constituent.	Soluble in 2½ parts cold water.	Soluble in 3 parts boiling HCl, specific gravity, 1.17.	Insoluble in boiling HCl.
Organic substances	0.0116	2.1380	....
CaO	0.0065	0.2436	0.3959
MgO	0.0022	0.2846	0.2023
Fe_2O_3	0.0045	1.5912	0.4398
Al_2O_3	0.0022	1.8480	5.3483
K_2O	0.0012	0.1950	2.1024
Na_2O	0.0027	0.0612	0.9588
SO_3	0.0035	0.0413	....
P_2O_5	0.0006	0.0863	....
Cl	0.0055	0.0059	....
SiO_2	0.0122	0.0930	78.5175
Insoluble	[a] 0.0082	87.9650	....
H_2O, 150°	....	5.2840	....
MnO	....	0.2412	....
Total	0.0609	100.08	87.97

[a] Insoluble on evaporating solution and heating residue. Soil contained also 0.0059 per cent NH_3, 0.0105 per cent N_2O_5, and 0.0673 per cent total nitrogen. No CO_2 present.

In these experiments 100 grams of soil were taken in 250 cm³ solution, which was filtered after three days. Grams absorbed = loss in 250 cm³ plus quantity dissolved from soil by 250 cm³ water alone.

Absorption shown by Küllenberg's experiments.

CAO.

Salt.	Equivalents per liter in original solution.	Amount of base absorbed.	
		Gram.	Per cent of original.
$CaSO_4$	0.01	0.0173	26.0
$CaSO_4$	0.02	0.0243	17.3
$CaSO_4$	0.04	0.0312	11.1
$Ca(NO_3)_2$	0.01	0.0066	9.8(?)
$Ca(NO_3)_2$	0.02	0.0180	13.5
$Ca(NO_3)_2$	0.04	0.0224	8.4
$Ca(NO_3)_2$	0.1	0.0257	3.8
$Ca(NO_3)_2$	0.2	0.0328	2.4
$CaCl_2$	0.01	0.0118	17.7
$CaCl_2$	0.02	0.0208	15.6
$CaCl_2$	0.04	0.0270	10.2
$CaCl_2$	0.1	0.0308	4.6
$CaCl_2$	0.2	0.0374	2.8

MGO.[a]

$MgSO_4$	0.01	0.0220	46.4
$MgSO_4$	0.02	0.0362	38.2
$MgSO_4$	0.04	0.0479	25.2
$MgSO_4$	0.1	0.0734	15.5
$MgSO_4$	0.2	0.1312	13.8
$Mg(NO_3)_2$	0.01	0.0238	50.2
$Mg(NO_3)_2$	0.02	0.0371	39.1
$Mg(NO_3)_2$	0.04	0.0470	24.8
$Mg(NO_3)_2$	0.1	0.0731	15.4
$Mg(NO_3)_2$	0.2	0.0815	8.6(?)
$MgCl_2$	0.01	0.0184	38.8
$MgCl_2$	0.02	0.0346	36.5
$MgCl_2$	0.04	0.0450	23.7
$MgCl_2$	0.1	0.0569	10.2(?)
$MgCl_2$	0.2	0.0985	10.4

[a] Anion of less influence here than with Ca.

Absorption shown by Küllenberg's experiments—Continued.

Na_2O.

Salt.	Equivalents per liter in original solution.	Amount of base absorbed. Gram.	Per cent of original.
Na_2SO_4	0.01	0.0140	18.9
Na_2SO_4	0.02	0.0216	14.6
Na_2SO_4	0.04	0.0372	12.6
Na_2SO_4	0.1	0.0849	11.5
Na_2SO_4	0.2	0.1211	8.2(?)
$NaNO_3$	0.01	0.0140	18.9
$NaNO_3$	0.02	0.0228	15.4
$NaNO_3$	0.04	0.0352	11.9(?)
$NaNO_3$	0.1	0.0889	12.6
$NaNO_3$	0.2	0.1460	9.9
NaCl	0.01	0.0112	15.2
NaCl	0.02	0.0229	15.4
NaCl	0.04	0.0463	15.7
NaCl	0.1	0.1020	13.8
NaCl	0.2	0.1638	11.1
Na_2HPO_4	0.005	0.0220	29.9
Na_2HPO_4	0.01	0.0414	28.1
Na_2HPO_4	0.02	0.0718	24.3
Na_2HPO_4	0.05	0.1567	21.2
Na_2HPO_4	0.1	0.2819	19.1
Na_2CO_3	0.01	0.0172	23.3
Na_2CO_3	0.02	0.0348	23.6
Na_2CO_3	0.04	0.0734	24.9
Na_2CO_3	0.1	0.1610	21.8
Na_2CO_3	0.2	0.2055	13.9

K_2O.

Salt.	Equivalents per liter in original solution.	Amount of base absorbed. Gram.	Per cent of original.
K_2SO_4	0.01	0.0609	54.5
K_2SO_4	0.02	0.0977	43.8
K_2SO_4	0.04	0.1496	33.5
K_2SO_4	0.1	0.2360	21.1
K_2SO_4	0.2	0.3503	15.7
KNO_3	0.01	0.0566	50.7
KNO_3	0.02	0.0840	37.6
KNO_3	0.04	0.1097	24.6
KNO_3	0.1	0.1658	14.9
KNO_3	0.2	0.3072	13.8
KCl	0.01	0.0630	56.5
KCl	0.02	0.0970	43.4
KCl	0.04	0.1084	24.3
KCl	0.1	0.1652	14.6
KCl	0.2	0.2833	12.8
K_2HPO_4	0.005	0.0713	63.9
K_2HPO_4	0.01	0.1271	56.9
K_2HPO_4	0.02	0.2113	47.4
K_2HPO_4	0.05	0.3295	29.5
K_2HPO_4	0.1	0.5005	22.4
K_2CO_3	0.01	0.0719	64.5
K_2CO_3	0.02	0.1989	53.3
K_2CO_3	0.04	0.2231	50.0
K_2CO_3	0.1	0.3094	20.6
K_2CO_3	0.2	0.3747	16.8

Absorption shown by Küllenberg's experiments—Continued.

NH_3.

Salt.	Equivalents per liter in original solution.	Amount of base absorbed.	
		Gram.	Per cent of original.
$(NH_4)_2SO_4$	0.01	0.0290	60.3
$(NH_4)_2SO_4$	0.02	0.0409	48.0
$(NH_4)_2SO_4$	0.04	0.0688	40.3
$(NH_4)_2SO_4$	0.1	0.1173	27.3
$(NH_4)_2SO_4$	0.2	0.1400	16.4
NH_4NO_3	0.01	0.0229	53.4
NH_4NO_3	0.02	0.0371	43.4
NH_4NO_3	0.04	0.0616	36.1
NH_4NO_3	0.1	0.0871	20.4
NH_4NO_3	0.2	0.1280	15.0
NH_4Cl	0.01	0.0229	53.4
NH_4Cl	0.02	0.0375	44.1
NH_4Cl	0.04	0.0612	35.9
NH_4Cl	0.1	0.0811	19.0
NH_4Cl	0.2	0.1174	13.8
$NH_4H_2PO_4$	0.01	0.0307	72.0
$NH_4H_2PO_4$	0.02	0.0535	62.8
$NH_4H_2PO_4$	0.04	0.0919	54.0
$NH_4H_2PO_4$	0.1	0.2000	47.0
$NH_4H_2PO_4$	0.2	0.3294	38.7
$(NH_4)_4H_2(CO_3)_3$	0.01	0.0260	61.1
$(NH_4)_4H_2(CO_3)_3$	0.02	0.0410	48.1
$(NH_4)_4H_2(CO_3)_3$	0.04	0.0744	43.7
$(NH_4)_4H_2(CO_3)_3$	0.1	0.1233	28.9
$(NH_4)_4H_2(CO_3)_3$	0.2	0.1755	20.6

Warington in 1868[a] studied "The part taken by oxides of iron and aluminum in the absorptive action of soils." He observed a slight decrease on measuring the concentration of potassium nitrate solution before and after contact with ferric hydroxide prepared by precipitation from ferric chloride solution with ammonia.

According to Van Bemmelen[b] the compounds resulting from such precipitation, commonly called hydroxides, are oxides containing variable amounts of water dependent on the condition as regards moisture of the atmosphere in which they are placed. There is some uncertainty as to what amount of the water of such substances should be counted as hydrate water and not as water diluting the solution. (See p. 24.) Warington assumes as combined water that quantity which is not given off over concentrated sulphuric acid, amounting to 15 per cent. His experiments are not described in sufficient detail to show to what extent this affects the results. With potassium chloride the case was similar, while potassium sulphate underwent greater absorption. As calculated by Warington the ferric oxide took up potassium equivalent to 0.2 per cent of its own weight of K_2O from potassium nitrate solution; 0.3 per cent from chloride, and 1.2 per cent from sulphate.

Ammonium sulphate or chloride solution became distinctly alkaline in contact with ferric oxide, a reaction which appears to be analogous to that between mercuric oxide and potassium chloride, etc., where,

[a] Jour. Chem. Soc., London, vol. 21, 1868, p. 1.
[b] Zeitschr. anorg. Chemie, vol. 20, 1899, p. 185, and other papers in the same journal.

owing to the very slight electrolytic dissociation of mercuric chloride, that compound forms in quantity, producing at the same time strongly alkaline potassium hydroxide.

Warington found that aluminum oxide was similar in behavior to ferric oxide, although its action was less marked. Rautenberg[a] had not been able to detect absorption on treating aluminum oxide with ammonium chloride solution.

According to Skey[b] quartz powder takes iron from ferric acetate solution. This requires verification.

In 1870 Lemberg began the publication of his work on the transformation of silicates by salt solutions. His experiments, whose number runs into the hundreds, constitute a mine of important observations in the chemistry of minerals and of geologic processes. The silicates used were in the main those related to the zeolites, but others were included. The solutions were chiefly of salts of the alkalies and alkaline earths, but embraced also such bases as iron, aluminum, silver, and thallium. The outcome of the experiments was usually either (1) exchange of bases in equivalent quantity between silicate and solution; (2) addition of base to the silicate, especially from alkaline solution; (3) addition of entire salt, or (4) addition or subtraction of water. Frequently, if not usually, transformation to a different mineral species, often crystalline in form, ensued. Most of the work was done at temperatures ranging between 100° and 200° C., although some of it was performed at ordinary room temperature. The first papers[c] contain studies of the action of magnesium salt solutions on such silicates as apophyllite, gehlenite, vesuvianite, datolite, and wollastonite; practically equivalent substitution of magnesium for calcium and potassium took place. The work with wollastonite was conducted at room temperature and also at 100° C., with the following results:

Action of magnesium sulphate on wollastonite.

	CaO.	MgO.
Wollastonite, original content	44.1	....
Wollastonite after contact with $MgSO_4$ solution:		
Two years at room temperature	27.4	11.5
Twenty-five days at 100° C	1.0	32.0

The action is the same in the cold as at 100°—an approximately equivalent exchange of calcium for magnesium.

Leucite at high temperatures was converted by sodium chloride solution into analcite,[d] while potassium chloride effected the reverse

[a] Jour. für Landw., vol. 7, 1862, p. 422.
[b] Trans. New Zealand Inst., vol. 2, 1869, p. 151.
[c] Zeitschr. deutsch. geol. Gesell., vol. 22, 1870, pp. 335 and 803; vol. 24, 1872, p. 187.
[d] Ibid., vol. 28, 1876, p. 537.

transformation. At low temperatures the reaction was likewise an equivalent exchange of bases. The reaction in the cold, although taking place to a less extent, is identical with that which results at higher temperature.

Leucite contains little water, while analcite has 8 or 9 per cent, and all the experiments, hot and cold, show an increase in water content as sodium takes the place of potassium. There seems to be no doubt that the one mineral was changed more or less completely into the other at 200° C., and the experimental results presented by Lemberg are evidence that the same transformation took place, less rapidly, at 100°, at 40°, and at room temperature. To bring out this point, and also to illustrate the nature of Lemberg's work, the results of his analyses in these experiments will be given in full.

The leucite and analcite were treated with concentrated solutions of the salts designated, and the portions which had undergone transformation were separated by levigation from the unchanged mineral, air-dried, and analyzed. The leucite was from Vesuvius, the analcite from the valley of Fassa.

Action of salt solutions on leucite.

	Leucite.	NaCl.	NaCl.	NaCl.	Na_2CO_3.	NaCl.	NaCl.
Temperature (deg. C.)		180–195.	100.	100.	100.	40.	Room.
Time (months)		([a])	4.	1½.	4.	11.	11.
H_2O	0.32	7.86	7.84	8.04	7.54	3.40	1.79
SiO_2	56.04	55.30	54.62	55.38	54.72	55.83	55.68
Al_2O_3	23.38	22.91	23.46	22.71	23.61	23.50	23.48
CaO	0.20	0.29	0.20	0.25	0.20	0.10	0.15
K_2O	18.90	0.68	0.66	0.89	1.40	11.61	15.88
Na_2O	1.41	12.96	13.22	12.73	12.54	5.56	3.02
	100.25	100.00	100.00	100.00	100.01	100.00	100.00

[a] 18 hours.

Action of salt solutions on analcite.

	Analcite.	K_2CO_3.	K_2CO_3.	KCl.	K_2CO_3.	K_2CO_3.
Temperature (deg. C.)		100.	100.	100.	40.	Room.
Time (months)		7.	4½.	3.	7.	13½.
H_2O	8.80	0.98	0.89	0.98	1.23	1.69
SiO_2	56.32	56.03	55.87	56.38	56.59	56.43
Al_2O_3	22.00	22.20	22.29	22.39	21.97	22.62
CaO	0.51	0.60	0.60	0.45	0.52	0.40
K_2O		19.60	20.31	19.80	20.23	17.82
Na_2O	13.19	0.57				1.04
	100.82	99.98	99.96	100.00	100.54	100.00

Clarke and Steiger,[a] by heating together dry salts and silicates, obtained, in crystalline form, substitution compounds of ammonium and other bases similar in composition to those here under discussion.

[a] Am. Jour. Sci., 4th ser., vol. 8, 1899, p. 245; vol. 9, 1900, p. 117.

To throw light on the question of so-called soil absorption, Lemberg subjected an artificial potassium alumino-silicate to digestion with various salts and salt mixtures in solution and analyzed the resulting solid after thorough washing. Sodium replaced potassium in increasing quantity as the concentration of the sodium chloride solution in contact with the solid was increased. The presence of potassium chloride in the solution at the outset lessened the extent to which substitution of sodium for potassium in the solid took place. Treated with ammonium chloride solution at room temperature, the artificial silicate gave up its potassium almost completely in exchange for ammonium, as did analcite its sodium at 40° and chabasite and desmin their calcium and sodium at 100°. Similar results followed experiments with other salts. The conclusion drawn by Lemberg from his own work and that of others is that "these are purely chemical processes, in which the mass plays a rôle in the sense of Berthollet's theory, hence the incomplete exhaustion of the solution and hence the mutual replacement of the bases."

Lemberg's work brings out over and over again the fact that sodium silicates and alumino-silicates are less stable in contact with water solutions than are the corresponding potassium compounds. Evidence of this is found not only in the laboratory, but also under natural conditions. The replacement of sodium in silicates by the potassium of a dissolved salt takes place far more readily than the reverse reaction. A similar relation, although perhaps not quite so marked, exists between magnesium and calcium silicates. The transformation of a magnesium silicate by calcium chloride into a calcium silicate is more difficult than the reverse change.[a] Wollastonite, apophyllite, gehlenite, okenite, and a number of artificial magnesium silicates were used to illustrate this experimentally. These phenomena are probably closely related to the relative solubility of the various minerals in water.

Lemberg,[b] following Bischof,[c] suggests the possibility that the need of plant life for potassium rather than sodium may be due to the fact that the potassium of silicates is held more tenaciously than the sodium, and accordingly the plant finds more of the potassium at its disposal in the soil; the environment has then developed the habit.

In this same connection we have a suggestion of one reason why the ocean is a solution of sodium rather than potassium chloride. Other metals and other bases have been eliminated owing to their greater capacity than the alkalies for forming compounds insoluble

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[a] Zeitschr. deutsch. geol. Gesell., vol 29, 1877, p. 483.
[b] Ibid., vol. 28, 1876, p. 599.
[c] Chem. Geol., 1st ed., vol. 1, p. 800.

in water, or, as in the case of nitrates, to the fact that they are readily decomposed in contact with other substances. The final persistence of the sodium salt rather than that of potassium may be due in large measure to this selective action of silicates in rocks, sediments such as mud, etc.

Lemberg was unable to detect transformation of the feldspars experimentally. "In addition to these (the zeolites) I have experimented with the various feldspars, hornblende, cordierite, serpentine, and scapolite, but up to the present only in the case of hornblende could an exchange of substance be proved with certainty."[a]

Work along the same line as that of Lemberg was continued by Thugutt.[b]

J. M. Van Bemmelen, of Leiden, in 1877 made an important contribution[c] to our subject, the first of an extended series by the same author. After a very comprehensive review of the work accomplished up to that date, he describes his own experiments.

One hundred grams of soil were brought into contact with 200 cm³ portions of solution containing respectively 8 and 40 milligram-equivalents of potassium chloride. After filtration the solutions were carefully analyzed, with the following results, expressed in milligram-equivalents. The author estimates the experimental error of a determination as at most ±0.2:

Results of Van Bemmelen's experiments with potassium chloride.

	8 mg. equivalents in 200 cm³.		40 mg. equivalents in 200 cm³.
	Experiment I.	Experiment II.	Experiment III.
K absorbed	6.07	5.96	15.50
Found in solution:			
Na	5.58	5.50	7.34
Ca	1.10	1.05	3.70
Mg	1.21	1.32	6.48
Total dissolved	7.89	7.87	17.52
Subtract bases dissolved by 200 cm³ water alone	1.50	1.50	1.50
	6.39	6.37	16.02
Discrepancy (excess dissolved over absorbed)	0.32	0.41	0.52

An exchange of potassium for sodium, calcium, and magnesium had taken place. The chlorine also was determined in the first experiment; it had not changed (8.19 equivalents found, instead of 8.0). The author remarks that the result does not show absorption of the salt as a whole; "it can be but very slight, if it takes place at all."

[a] Zeitschr. deutsch. geol. Gesell., vol. 28, 1876, p. 591.
[b] Dissertation, Dorpat, 1891, and Zeitschr für anorg. Chemie, vol. 2, 1892, pp. 64-156.
[c] Landwirtschaftliche Vers. Stat., vol. 21, 1877, pp. 135-191.

Van Bemmelen later[a] investigated the behavior of hydrous silica toward various solutions. The silica used, although containing water in an amount represented by the formula $SiO_2,4H_2O$, of which 3.8 H_2O was given off on drying at 100° C. or over concentrated sulphuric acid, was a dusty powder. The result of putting this substance into salt solutions was practically the same as if the loosely bound water of the silica had been added as liquid. The solute distributed itself almost uniformly between the water of the solution and the water of the colloid.

The quantities taken for experiment were 100 cm³ of solution and 10 grams of silica. The 3.8 molecules of water loosely held by the silica amount to 5.18 cm³ in 10 grams of the powder, and in case this acts as solvent water the concentration would be that corresponding to dilution to 105.18 cm³. The solutions, analyzed after contact with the solid, were actually of concentrations corresponding to dilution to the following volumes:

Results of Van Bemmelen's experiments with hydrous silica, showing volumes corresponding to observed concentration.

	1.	2.	3.
Equivalents[a] originally in 100 cm³	20	50	100
Solution used:	*Cm³.*	*Cm³.*	*Cm³.*
K_2SO_4	105.3	105.2	104.8
KNO_3	104.7	104.4	....
KCl	104.4	104.5	....
H_2SO_4	105.8	104.5	104.2
HNO_3	104.4	104.5	104.2
HCl	104.2	104.7	104.3

[a] As used by Van Bemmelen, equivalent, atom, and molecule signify the respective weights taken in milligrams.

How much of the water of the solid is to be counted as taking up the solute and how much of it is in a condition in which it will not act as solution water can not, according to Van Bemmelen,[b] be determined; the assumption that 3.8 molecules perform that function may therefore be subject to modification. In the experiments just cited somewhat less salt was, as a rule, absorbed by the silica than this assumption would require. Van Bemmelen is inclined to regard the action as an exchange between colloid and solution, the colloid taking up salt and giving off an equivalent quantity of water.

In a later paper,[c] speaking of absorption by the soil, Van Bemmelen says: "If absorption of the entire salt takes place it is slight, and in any case not greater than with silica." A certain soil after removal of all matter soluble in hydrochloric acid and drying at 110°

[a] Jour. für prakt. Chemie, vol. 23, 1881, p. 327; also Land. Vers. Stat., vol. 23, 1879, p. 264.
[b] Zeitschr. für anorg. Chemie, vol. 23, 1900, p. 330, and other volumes of the same journal.
[c] Landw. Vers. Stat., vol. 35, 1888, p. 121.

took up 12.8 per cent moisture from moist air. "The water thus absorbed plays the same part, so far as the salt is concerned, as the water of the solution." Contact with this soil dried at 110° did not alter the concentration of chlorine in a potassium chloride solution; the concentration before contact was 20.13 milligram-equivalents in 100 cm^3; after contact it was 20.18. Therefore the dried powdered material did not extract water as such from the solution; had it done so the concentration of the solution would have increased about 5 per cent. The salt is, as in the case of the silica, uniformly distributed between the water of the solution and any water taken up by the solid. There is no absorption of the salt alone, although there may be absorption of the unchanged solution. The same soil, containing 12.8 per cent moisture, decreased the chlorine concentration to the same extent as would the water it contained if added as liquid to the solution. In his summing up at the conclusion of this paper Van Bemmelen says: "The absorption phenomena of the soil are to be ascribed chiefly to colloid silicates, whose power of absorption for entire salts is slight (ein geringes)."

As late as 1900 Van Bemmelen writes:[a] "As to a specific absorption, these complexes (colloid silicates) exert none or almost none; if salts are absorbed, the absorbed water is the chief cause therefor."

The important practical fact here is that colloid silica and colloid silicates as they occur in nature do not possess in any large measure the power of abstracting from solution and concentrating neutral salts. Water percolating through such material will share its dissolved salts with the water of the colloid; but there can be no notable accumulation of salt except as it is present in corresponding quantity in the solution both before and after contact with the siliceous matter.

A paper published by Lagergren in 1899[b] on the "Theory of the so-called adsorption of dissolved substances," describes experiments on the action of animal charcoal, kaolin, and powdered glass on the dissolved salts of the alkalies, barium, and magnesium. The author found that charcoal and kaolin dried at 160° C. *increased* the concentration of chlorides and bromides, in some cases as much as 1 per cent; the concentration was determined by specific gravity and by titration with silver nitrate. The data given do not show how well these methods agreed. The charcoal and kaolin had been boiled with hydrochloric acid in order to purify them. In the case of the sulphates specific gravity alone was relied upon for the determination of concentration. The charcoal contained considerable mineral matter. In view of the importance of the matter, confirmation of Lagergren's results seems desirable.

[a] Zeitschr. anorg. Chemie, vol. 23, p. 321.

[b] Bihang till k. Svenska Vet.-Akad. Handlingar, Bd. 24, Afd. II, No. 4, 1899.

Joly[a] showed that sea water attacks basalt, orthoclase, obsidian, and hornblende to a much greater extent than does fresh water.

Dittrich[b] found that the action of salt solutions on a decomposed hornblende granite consisted in an exchange of bases. Neutral potassium chloride solution dissolved from the rock almost twice as much calcium as dilute acetic acid, and about one-fourth as much as warm 10 per cent hydrochloric acid. Neither carbonic nor acetic acid dissolved more than a small part of the potassium taken from solution by the rock powder. Potassium, ammonium, and magnesium chlorides had approximately equal effect on the powdered granite, while the action of sodium chloride was much weaker, and calcium chloride scarcely produced any change whatever. The action was the same whatever the acid with which the base was combined.

Powdered feldspar or kaolin with potassium chloride solution gave but little action. "Beide Versuche hatten also ein negatives Resultat gegeben." The experiments did show, however, that simple absorption of the potassium had not taken place.

Laterite and bauxite with potassium chloride solution retained but small quantities of potassium, which, in contrast to that taken up by silicates, was almost completely redissolved by water. A slight exchange also took place between the calcium of the solid and the potassium of the salt. In one experiment with laterite 0.0048 gram CaO and a trace of magnesium oxide went into solution, while potassium equivalent to 0.0298 gram potassium oxide, out of a total of 0.4680 gram, was taken up by the 25 grams of the solid. "These experiments prove most clearly that the phenomena under investigation are not absorption phenomena, but are purely chemical processes." Hydrous aluminates of calcium and magnesium the author considers responsible for the absorption of potassium in the earth's crust.

As affording definite data regarding the substances dissolved from a rock of the character mentioned, a part of Dittrich's results will be reproduced in detail. The decomposed rock contained 0.90 per cent calcium oxide, 1.50 per cent magnesium oxide, 7.73 per cent potassium oxide, 1.72 per cent sodium oxide; 25 grams rock powder were taken in each instance with 100 cm³ salt solution.

Quantities, in grams, dissolved from rock, by N/10 NaCl (0.5806 gram in 100 cm³).

CaO	0.0356
MgO	0.0050
K_2O	Trace.

About one-eighth of the total sodium was removed from solution by the rock. The total bases in the solution are equivalent to 0.5981

[a] Joly, J., Proc. Roy. Irish Acad., vol 24, 1902, pp. 21-33.
[b] Mitt. grossh. bad. geol. Landesanstalt, vol. 4, 1903, p. 341.

gram NaCl, an excess of 0.0175 gram over that originally present. This excess is for the most part accounted for by the solubility of the rock constituents in water alone.[a] Chlorine, 0.3493; originally 0.3518 gram.

Quantities, in grams, dissolved from rock by N/10 KCl (0.7404 gram in 100 cm^3).

CaO	0.0640
MgO	0.0056
Na_2O	0.0169

About two-sevenths of the potassium was precipitated. The total bases in solution were equivalent to 0.7600 gram KCl, greater by 0.0196 gram than the original amount. Chlorine 0.3468; originally 0.3518.

N/10 $MgCl_2$ (0.4750 gram in 100 cm^3) gave 0.0630 CaO and small quantities of K_2O and Na_2O. About one-fifth of the magnesium was precipitated. Lime and magnesia in solution were equivalent to 0.4888 gram magnesium chloride, an excess of 0.0138 gram over that originally present.

Alkali nitrates, sulphates, and carbonates gave similar results. Calcium chloride had little effect. Dittrich continued this work and published its results.[b]

Briggs[c] investigated the action of dilute solutions on powdered quartz whose particles were for the most part 0.005 to 0.05 millimeter in diameter, corresponding to a total area of about 1,000 cm^2 per gram.

No change in the concentration of neutral salts could be detected after contact of their solutions with quartz, and the author's conclusion is that "so far as quartz is concerned adsorption is of minor importance in the retention of soluble substances in the soil."

Cushman, in the microscopic appearance of the particles and in the formation of a considerable quantity of soluble alkali silicate on wet grinding, found experimental evidence that water produces a colloidal siliceous film on the surface of powdered orthoclase and other silicates.[d]

So far as the evidence goes, then, the action of silicates, clay, and other constituents of the earth's crust on solutions of such salts as do not dissolve in water with alkaline reaction consists in an equivalent exchange of bases. The salt is uniformly distributed between the water of colloid silica and silicates and the water of the solution. Any absorption of the salt as a whole by the solids mentioned is so slight as to have escaped positive detection. As bearing on the latter point it should be said that certain colloid substances, analogues to which are present in the earth's crust, do take from solution both the

[a] Loc. cit., p. 206.

[b] Zeits. für anorg. Chem., vol. 47, 1905, pp. 151-162.

[c] Jour. Phys. Chem., vol. 9, 1905, p. 617.

[d] U. S. Dept. Agr., Bureau of Chem., Bull. 92, 1905.

acid and the base of the salts mentioned. Ferric and aluminum oxides and metastannic and stannic acids, for instance, take potassium sulphate from solution, while hydrated manganese dioxide takes up sulphate, chloride, or nitrate of potassium.[a] This of course does not necessarily imply adsorption. It is not at all impossible, as Van Bemmelen suggests, that chemical reaction takes place. Manganese dioxide takes up more base than acid from a neutral salt solution, and thus imparts to the solution acid reaction. Cupric oxide takes more of the acid and alkalinity of solution results.[b] These and other similar reactions suggest the reaction between mercuric oxide and potassium chloride, where potassium hydroxide forms owing to the slight electrolytic dissociation of mercuric chloride, and they may be due to similar causes. The solids capable of absorbing both acid and base from a neutral salt solution are in the main those which themselves exercise both basic and acidic functions.

It is interesting that Van Bemmelen, about six years before the propounding of Arrhenius's theory, uses the old electrolytic dissociation theory of Clausius to interpret these reactions: "If we assume with the physicists (as in the explanation of electrolysis) that in a dilute acid or salt solution a few individual molecules are in a state of dissociation, it is conceivable that the potash of these molecules is bound by the manganese dioxide, whereupon fresh dissociation and binding of potash can take place until equilibrium sets in."[c]

ALKALINE SOLUTION.

Where the solution is alkaline in reaction, containing a soluble hydroxide dissolved as such or a salt made up of a strong base and a weak acid (as the carbonates, silicates, and phosphates of sodium and potassium) which is hydrolyzed by water with resulting formation of free alkali, its behavior with clay, soils, etc., is due largely to the presence of colloid silica or aluminum silicate, and consists primarily in the direct addition of alkali to these solids, without substitution, insoluble silicates or alumino-silicates being formed.

Way[d] was the first to observe that the absorption of free alkali (potassium hydroxide) by clay was greater after the clay had been extracted by hot hydrochloric acid. He, however, attached little importance to the observation. The same fact was noted by Van Bemmelen[e] and attributed to the union of the alkali with silicic acid remaining after decomposition of silicates by the hydrochloric acid. That free alkali was taken from solution by soils without substitution by other bases was observed by Henneberg and Stohmann[f] in the

[a] Van Bemmelen, Jour. für prakt. Chemie, vol. 131, 1881, p. 330.
[b] Tommasi, Comptes rendus, vol. 92, p. 453.
[c] Loc. cit., p. 394.
[d] Jour. Roy. Agr. Soc., vol. 11, 1850, p. 359.
[e] Landw. Vers.-Stat., vol. 21, 1877.
[f] Ann. Chem., vol. 107, 1858, p. 152; Jour. für Landw., vol. 3, 1859, p. 25.

case of ammonia, and later by others in the case of other bases. That the extraction with acid by decomposing soluble silicates or coating them with an impervious layer of silicic acid in large measure destroys the power of absorption with substitution was shown by Peters,[a] Eichhorn,[b] and others.

The fact that silicates after extraction with acid are capable of taking up free alkali led Heiden[c] to an astonishing observation. In order to remove silica after extraction with acid he digested with sodium carbonate solution and was surprised to find that the residue took up 3½ times as much potassium from potassium chloride solution as before the sodium carbonate treatment. Sodium had been taken up by the silica, and this was then in a position to enter into exchange with potassium in neutral solution.

The decrease in concentration observed by Briggs[d] on treating potassium, sodium, and ammonium hydroxide solutions with quartz (100 grams quartz powder, 150 cm^3 solution) in glass flasks was approximately the same in the three cases.

Absorption of alkali by quartz.

Final concentration.	Loss, 150 cm^3.
	Millimol.
0.105 millimol in 150 cm^3	0.042
13 millimols in 150 cm^3	0.8

Carbonates suffered a slighter loss in concentration under similar conditions. That this action was due chiefly to the glass of the flask rather than to the quartz was shown by the fact that the results with potassium hydroxide in a platinum container were only about one-sixth those in glass.

The author recognizes that "the carbonate and hydroxide can not be considered free from chemical action on the quartz."

Rümpler[e] discusses these reactions in connection with the fact that sugar-makers purify beet juices by filtration through a silicate (an artificial cement) which takes out practically all of the potassium and about 25 per cent of the nitrogenous bases (betain), thus leaving the molasses less viscous and capable of further crystallization. He points out that when free alkali (potassium hydroxide) acts on a silicate the calcium and magnesium which are removed are at once precipitated as hydroxides and therefore do not tend to put a stop to further substitution of potassium by promoting the reverse reaction, as their soluble salts would do. This is suggested as a reason why free alkali has greater action on silicates than a neutral salt has.

[a] Landw. Vers.-Stat., vol. 2, 1860, p. 146.
[b] Jahrb. Fortschr. Agr. Chem., vol. 2, 1859, p. 16.
[c] Düngerlehre, vol. 1, p. 257; cited by Lemberg.
[d] Jour. Phys. Chem., vol. 9, 1905, p. 617.
[e] Ber. Int. Cong. angew. Chemie, 1903, vol. 3, p. 59; also Die deutsche Zucker-Industrie, vol. 26, 1901, pp. 585 and 625.

PRECIPITATION OF ACID ION.

The loss of the acid radical of a dissolved salt to clay, soil, etc., appears, like the loss of the base, to be due usually to the formation of an ordinary insoluble salt, such as the phosphate, carbonate, or silicate of calcium, iron, etc. Such precipitation takes place primarily from alkaline solution because the acids that have the greatest tendency to form insoluble compounds are weak acids, whose salts are hydrolyzed by water. It is observed also in such solutions as those obtained by dissolving calcium carbonate or calcium phosphate in carbonic acid solution.

Way[a] notes the fact that the acids of ammonium carbonate, potassium carbonate, calcium bicarbonate, sodium phosphate, calcium acid phosphate, etc., are removed from solution by soils, together with the bases. Now the base of the dissolved salt in contact with these soils is substituted chiefly by calcium. When the calcium salt is soluble, therefore, as in the case of the chloride, nitrate, and sulphate, the acid radical remains in the solution; when the calcium salt is insoluble, as in the case of the carbonate or phosphate, the acid radical is precipitated.

Liebig[b] showed that the acid radical of sodium and potassium silicates was removed in part by soils. According to Küllenberg[c] the phosphate radical is taken up by soil from solution in greater quantity the higher the atomic weight of the metal with which it is combined (potassium, sodium, ammonium). The difference is probably due to the varying readiness with which the salts of the different metals decompose the silicates of the soil.

Warington[d] attributes the removal of the phosphate radical from solution by soils chiefly to interaction with ferric and aluminum oxides with formation of insoluble phosphates. He shows that the oxides mentioned when artificially prepared are changed to phosphates by a solution of calcium phosphate in water containing carbonic acid. Ferric oxide (moist, prepared by precipitation from ferric chloride solution with ammonia) takes up about 6 per cent of its weight of potash (K_2O) from a 1 per cent solution of potassium carbonate. From 0.4 to 0.8 equivalent of the carbonate radical is absorbed for one of potassium. By the same oxide 2.3 per cent of potassium sulphate is taken up, 6 per cent of ammonium carbonate (equivalent quantities of base and acid), 2.5 per cent of ammonium sulphate, and 0.24 per cent of ammonium chloride, a 1 per cent solution of the salt being used in each case. The ammonium salt solutions are distinctly alkaline after contact with ferric oxide. Aluminum oxide gives results similar to those with ferric oxide, but less strongly marked.

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[a] Jour. Roy. Agr. Soc. vol. 11, 1850, loc. cit.
[b] Ann. Chemie, vol. 105, 1858, p. 109.
[c] Jahrb. Fortschr. Agr. Chem., vol. 8, 1865, p. 15.
[d] Jour. Chem. Soc. London, vol. 21, 1868, p. 1.

Van Bemmelen[a] showed that extraction with hydrochloric acid, which dissolved oxides of iron and aluminum and decomposed silicates to such an extent that absorption with substitution would not take place, also did away with precipitation of the carbonate, phosphate, and borate radicals by the soil. A soil thus extracted took up half the alkali from sodium carbonate solution, leaving the acid radical in its entirety as bicarbonate. From a solution of sodium phosphate (Na_2HPO_4) such a soil took up 7.6 equivalents sodium out of a total of 38.8 present, leaving the acid radical practically unchanged. From a borax solution it took 5 equivalents sodium out of a total of 9, and no boron. The same soil before extraction with hydrochloric acid took 12 equivalents of sodium and 4.6 milligram-atoms of phosphorus from a sodium-phosphate solution containing 38.8 equivalents of sodium and 19.4 milligram-atoms of phosphorus.

These facts are in harmony with the conclusion above stated—that the abstraction of acid radical from solution by silicates is due to the formation of insoluble salts, the basic constituents capable of forming these insoluble salts being removed or rendered inaccessible to the solution by the action of hydrochloric acid.

INFLUENCE OF CALCIUM CARBONATE.

The action of such silicic acids as result from extraction of a silicate or a soil with acid, as in the experiments of Van Bemmelen just cited, is of some practical importance where calcium carbonate is present, giving to the mixture an alkaline reaction. In such a case, as has been shown, the free alkali unites with the silicic acid and is thus precipitated. The consequence of this is that more calcium carbonate dissolves to replace the calcium hydroxide removed, and these processes repeat themselves until equilibrium is reached. The extent to which the solubility of calcium carbonate is increased by the presence of a soil which has been extracted with hydrochloric acid is shown by the following data from Van Bemmelen.[b] "Soil B" designates the soil extracted with hydrochloric acid.

250 cm^3 water dissolve 0.30 milligram-equivalent calcium carbonate.

250 cm^3 water in the presence of 100 grams soil B dissolved 2.4 milligram-equivalents.

"Soil B" in contact with calcium carbonate not only thus increases the amount of the latter which may be held in solution by a water, but it becomes itself capable, through the medium of the calcium carbonate, of reaction with neutral salts. Again citing Van Bemmelen,[c] 250 cm^3 potassium chloride solution (50 equivalents) dissolve 0.73 equivalent calcium carbonate. But in the presence of 100 grams of soil B, 250 cm^3 of the same solution dissolve from calcium carbonate

[a] Landw. Vers.-Stat., vol. 23, 1879, p. 267. [b] Landw. Vers.-Stat., vol. 23, 1879, p. 273. [c] Loc. cit.

6.2 equivalents of calcium and 4.2 of the carbonate radical, while 4 equivalents of potassium are taken up by the soil owing to partial double decomposition between calcium hydroxide and potassium chloride with resultant formation of potassium hydroxide, which combines with the silicic acid.

In similar experiments with amorphous silica containing water corresponding approximately to the formula $SiO_2,4H_2O$, calcium carbonate alone was but little affected by the silica, and potassium chloride solution not at all, but when 20 grams silica, 2 grams calcium carbonate, and 200 cm^3 (40 equivalents) potassium chloride solution were mixed it was found that 3.8 milli-equivalents of calcium and 2.7 of the carbonate radical were dissolved and 2 of potassium were taken up by the silica.

Lemberg had somewhat earlier[a] brought out experimentally the same point with regard to the influence of calcium carbonate. He used carbonic acid solution for extracting the alkali from an artificial zeolite-like potassium alumino-silicate,[b] and the behavior of the resultant silicic acids toward calcium carbonate and neutral salt solutions was similar to that of Van Bemmelen's soil B, which had been extracted with hydrochloric acid. Lemberg's discussion of this reaction is well worth reproducing:[c]

These experiments show what essentially different courses chemical-geological transformations may take, according to the electro-negative constituent of the salt solution which causes the metamorphism. Consider a carnallite bed underlain by layers of clay, and suppose the clay to be transformed in places into some product rich in potash, such as a mica. It is natural to attribute the potash content of the metamorphic product to the overlying carnallite; the fact remains unaccounted for, however, that the entire body of clay has not undergone the same change. The matter is thrown into a very different light when it is found that the altered portions of the clay carry calcium carbonate, while the surrounding portions are free from it. If the clay possesses a composition similar to that of the silicate extracted with carbonic acid in the experiments described, the percolating potassium chloride solution will be without action on it; contact of the solution with calcium carbonate, however, will cause partial change into calcium chloride and potassium carbonate, and the latter salt, being alkaline, is capable of changing the clay into a potash silicate. As the altered clay has taken up no calcium one would scarcely be likely to connect the mechanically admixed calcium carbonate with the metamorphism, and yet it has been the conditio sine qua non; still more difficult to clear up would the process be if the calcium carbonate had been completely dissolved out and the last clue thus destroyed.

As the transformation of this clay is conditioned by the calcium carbonate, so, on the other hand, the solubility or alterability of the calcium carbonate is affected by the presence of the clay. Of two marls, one a clay capable of taking up alkali and the other a chloritic clay, the former, other things being equal, will in a fixed time give up more lime in the form of calcium chloride to waters containing sodium and potassium chlorides than the latter.

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[a] Zeitschr deutsch. geol. Gesell., vol. 28, 1876, p. 593

[b] Original K_2O content, 22.8 per cent; after extraction with CO_2, 5.3 per cent.

[c] Loc. cit., p. 594.

Such modifications of one chemical process by another may be of frequent occurrence, and the striking fact that rock masses apparently perfectly homogeneous suffer at points but little apart very different transformations, loses in a measure its puzzling character in view of the above considerations.

APPLICATION OF MASS LAW.

A paper by H. P. Armsby, written in 1877,[a] contributed toward a clear understanding of the nature of the absorption of bases by silicates. Way and other workers on the subject had been embarrassed in attempting to classify the observed phenomena as chemical reactions by the fact that no relation of chemical equivalence existed between the quantity of base taken up and the quantity of any single constituent or of any group of constituents of a soil present under the conditions of the experiment. Nor could such a relation be found among the quantities of different bases taken up by a fixed amount of one soil. Even among compounds of the same base the absorption from a solution of the hydroxide or salt alkaline in reaction was not as a rule the same as from solutions of the neutral salts. Further, the absorption of base by a given soil from the same salt was by no means invariably the same, but fluctuated with temperature, concentration of the solution, and relative quantities of soil and solution. These facts were used as arguments in favor of the theory that absorption was a physical surface phenomenon.

All these things, Armsby points out, are in accordance with the law of mass action. The absorption had been shown to be an exchange of bases between the silicates of the soil and the dissolved salts. In the specific case which he takes up experimentally—the reaction between calcium chloride and an artificial sodium alumino-silicate—there is opportunity for the formation of two slightly soluble substances, one the sodium alumino-silicate, the other the corresponding calcium compound. In such a case reaction in general does not proceed to the formation of one of the two substances exclusively to the absolute wiping out of the other, but an equilibrium condition is reached in which both slightly soluble compounds are present. When such equilibrium sets in a definite relation prevails among the concentrations of the reacting substances in the solution. When calcium chloride solution, for example, is brought into contact with solid sodium alumino-silicate equilibrium may require sodium in solution in excess of calcium. In such case solid calcium alumino-silicate will form, withdrawing calcium from and supplying sodium to the solution until the necessary ratio is reached. The amount of solid transformed will therefore vary with the amount and concentration of the solution used as well as with the nature of the solute. Sodium chloride in this case accumulates in the solution until its

[a] Landw. Vers.-Stat. 21, 397.

tendency to react with the newly formed calcium alumino-silicate, producing again the original substances, holds in check the tendency of the first reaction to take place.

In illustration of this Armsby shows that the absorption of calcium falls off when sodium chloride is present in the solution from the beginning with calcium chloride:

Absorption of calcium by silicate, in grams.

Amount of silicate taken.	Absorption, NaCl present.	Absorption, NaCl absent.
2.5	0.1151	0.1039
1.25	0.0663	0.0585
0.625	0.0359	0.0303
0.3125	0.0187	0.0143

The sodium chloride was added in quantity about equivalent to the calcium chloride.

The amounts of different bases absorbed will vary with the solubility of their respective alumino-silicates and change in temperature, by shifting the relative solubility, may lead to readjustments in the equilibrium.

In the transformation of analcite into leucite by potassium chloride [a] change of one solid into the other may be expected to take place until the composition of the solution is such that it acts upon neither analcite nor leucite. The simplest case of such a solution is that which results when a mixture of analcite and leucite is treated with water, forming a solution saturated with respect to both solids. The ratio of potassium to sodium in this solution gives at least a qualitative indication of what may be expected for the equilibrium ratio where potassium and sodium salts are in contact with the two minerals.

Leucite, the potassium compound, appears to be less soluble than analcite. It may then be expected that any solution in equilibrium with the two will contain less potassium than sodium and that in solutions not fulfilling this condition transformation of the one solid into the other will take place until this equilibrium condition is satisfied. A potassium salt will therefore transform more of analcite than a sodium salt will of leucite under similar conditions.

INFLUENCE OF CONCENTRATION.

Bödeker in 1859 [b] sought a numerical expression for the relation between concentration of solution and amount of absorption. It was known that increased reaction followed rise in concentration, although not in the same proportion. Bödeker concluded that the absorption was proportional to the square root of the concentration.

[a] See p. [illegible].

[b] Journ. für Landwirtschaft, [illegible] 1859, p. [illegible].

a statement which expresses the facts approximately in some cases, but which has been found not to hold in general. Within certain limits of concentration—50 to 500 milli-equivalents salt per liter—it is true that to double the amount of absorption the concentration must be approximately quadrupled, but in weaker solutions absorption is more nearly directly proportional to concentration, while in more concentrated solution the quantity of any given base taken up by a fixed amount of soil is but little affected by varying the concentration of the solution.

Wolff[a] in the same year called attention to the fact that the final, not the initial, concentration of the solute is to be considered in discussing the relation between strength of solution and amount of absorption. According to him, two equal quantities of soil treated with different solutions of a salt will have absorbed identical quantities of base, if after absorption the percentage compositions of the solutions are alike.

This phase of the subject was worked out experimentally for colloids by Van Bemmelen, who showed that the quantity of solute taken up by a given quantity of a colloid was the same, no matter what the original conditions, if only the final concentration of the solution was the same. Among the data illustrating this are the following, 100 millimols metastannic acid (SnO_2 with about $2H_2O$) being used in each case:[b]

Experiments with sulphuric acid and colloid metastannic acid.

Initial state.			Final state.		
Mols[a] H_2SO_4.	Cm³ H_2O.	1 mol H_2SO_4 in cm³.	Mols H_2SO_4 taken up by solid.	Mols H_2SO_4 in solution.	1 mol H_2SO_4 in cm³.
20	10	½	11.45	8.55	1.17
50	50	1	11.2	38.8	1.29
10	10	1	8.55	1.45	7.0
20	80	4	8.52	11.48	7.1
10	20	2	8.07	1.93	10.4
50	400	8	8.21	41.79	9.56
10	40	4	7.4	2.6	15.4
20	200	10	7.5	12.5	16.0

[a] As used by Van Bemmelen, the mol is the molecular weight taken in milligrams.

Therefore the quantity of salt absorbed by the colloid will be determined by the final concentration of the solution. Water percolating through colloid material will give up its solute to the colloid until equilibrium is reached. After that it will pass through unchanged. A more dilute solution will extract the salt from the colloid until an equilibrium which corresponds to the greater dilution is established.

[a] Landw. Zeitung für Nord- und Mitteldeutschland, 1859, Nos. 32 and 33. Cited by Peters.
[b] Jour. prakt. Chem., vol. 131, 1881, p. 333.

The absorption is accordingly, in general, an exponential function of the concentration of the solution. This is the form found by Ostwald[a] for the solubility of the alkaline earth sulphates in acids of various concentrations and by Meyerhoffer[b] for the action of potassium carbonate on barium sulphate. This form of the curve is therefore not necessarily an indication that we are dealing with solid solution or adsorption.[c] The chief reaction where silicates and salt solutions are concerned appears from the stoichiometrical relations to be undoubtedly double decomposition. Where the reaction consists chiefly in the precipitation of metal hydroxide, as with orthoclase or kaolin and cupric sulphate, the silicate, owing to the weakness of its acid and the consequent tendency of the anion to unite with the hydrogen of water to form the nondissociated acid, acts in a sense as a generator of hydroxyl ions, and here the exponential form of the concentration curve is to be expected. It is to be borne in mind that the conditions examined experimentally are not those of equilibrium, inasmuch as precipitation may be increased by further grinding of the silicate powders. The greater penetrative power of the concentrated solutions, due to their higher osmotic pressure, will undoubtedly determine in some degree the extent of the reaction and therefore the form of the concentration curve.

Van Bemmelen regards the holding of electrolytes by colloids as due to loose chemical combination, and designates the resulting products as "absorption compounds." In many of the cases examined by him ordinary chemical union undoubtedly is responsible for a part, at least, of the phenomena observed, as where stannic oxide is treated with acid or alkali. In some other cases there seems reason to classify the facts as distribution of solute between two solvents—one water, the other a colloid.

No undoubted case of solid solution is known among amorphous substances.[d]

As to the possibility of adsorption, Freundlich[e] finds that even by charcoal "inorganic salts in water solution are very weakly adsorbed." Indubitable evidence that adsorption of inorganic salts by mineral matter takes place to a measurable extent seems to be lacking.

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[a] Jour. prakt. Chem., vol. 137, 1884, p. 55.

[b] Zeitschr. phys. Chem., vol. 53, 1905, p. 530.

[c] For a discussion of adsorption, solid solution, and chemical combination see Ostwald, Lehrbuch vol. 2, pt. 3, 1906, pp. 252 and ff.

[d] Ostwald, Lehrbuch, vol. 2, pt. 3, 1906, p. 253.

[e] Freundlich, Herbert, Adsorption in solutions: Zeitschr. phys. Chem., vol. 57, December, 1906, pp. 385–470.

EXPERIMENTAL WORK.

METHOD OF PROCEDURE.

In the work carried out in the Geological Survey laboratory[a] the experimental procedure, except where otherwise specified, was as follows: The mineral, finely ground in an agate mortar, was left several days at room temperature, with occasional shaking, in a well-stoppered flask with twice its weight of the solution. Whether contact was for a few hours or a few months made little difference. The liquid was filtered through a double layer of filter paper in a Gooch crucible, which, except in the case of pure-water extracts, retained the finest powders and gave perfectly clear filtrates. A measured quantity of the filtrate was subjected to analysis. After addition of acid, silica was removed by evaporation, iron and aluminum were precipitated with ammonia, and calcium was separated with ammonium oxalate. Ammonium salts were then driven off by heating, and magnesium was precipitated and washed with barium hydroxide solution and weighed as the sulphate. The barium hydroxide contained a trace (less than 0.1 per cent) of impurity, chiefly potassium and sodium, for which a correction was applied in the one or two cases in which it was of significance. In the filtrate from magnesium hydroxide barium was precipitated with ammonium carbonate, reprecipitated, and the alkalies in the filtrate were weighed as chlorides and separated in the usual way. Repeated tests of the alkali chlorides for magnesium gave, as a rule, an unweighable trace at most—rarely a few tenths of a milligram.

Some idea of the degree of uniformity which can be obtained on repeating these experiments as nearly as possible under the same conditions may be had from the duplicate results with copper sulphate and kaolin. The errors may, however, in less favorable cases, amount to several hundredths of a millimol.

The results are only roughly comparable among different minerals, owing to the impossibility of getting the powders of uniform fineness.

The orthoclase was, except where otherwise specified, from a lot of very fresh cleavage fragments obtained from Delaware County, Pa., through Foote & Co. Orthoclase A and orthoclase B were from San Diego County, Cal.

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[a] A preliminary paper giving some of the results of this work was published in Jour. Am. Chem. Soc., vol. 27, 1905, pp 976-979, and in Economic Geology, vol. 1, 1905, pp. 67-73.

EXPERIMENTAL RESULTS.

KAOLIN AND CUPRIC SULPHATE.

Kaolin with twice its weight of cupric sulphate solution. The kaolin used was an impalpable powder, most of its particles having a diameter of about 0.002 to 0.003 mm. Examination under the microscope, kindly made by Mr. Lindgren, showed the presence of some undecomposed feldspar. The kaolin was free from carbonate and gave no trace of hydrogen sulphide on heating with acid. The results are stated both in grams and in milligram molecules.

Experiments with kaolin and cupric sulphate solutions.

COPPER FOUND IN 50 CUBIC CENTIMETERS.

	1.		2.		3.		4.		5.	
	Grams.	Millimols.	Grams.	Millimols.	Grams.	Millimols.	Grams.	Millimols.	Grams.	Millimols.
Originally	0.0051	0.08	0.0254	0.40	0.0259	0.41	0.1269	2.00	0.1268	1.99
Finally	0.0013	0.02	0.0143	0.22	0.0156	0.25	0.1104	1.74	0.1099	1.73
Loss	0.0038	**0.06**	0.0111	**0.18**	0.0103	**0.16**	0.0165	**0.26**	0.0169	**0.26**

BASES FOUND IN VARIOUS VOLUMES OF FILTRATES.

Constituent.	110 cm³.		50 cm³.		55 cm³.		60 cm³.		60 cm³.	
	Grams.	Millimols.	Grams.	Millimols.	Grams.	Millimols.	Grams.	Millimols.	Grams.	Millimols.
SiO_2	0.0026	......	0.0026	......	0.0006	......	0.0020	......	0.0013	......
Fe_2O_3, Al_2O_3	0.0008	[a] 0.02	0.0020	0.06	0.0004	0.01	0.0018	0.05	0.0025	0.07
CaO	0.0042	0.08	0.0048	0.09	0.0051	0.09	0.0066	0.12	0.0066	0.12
MgO	0.0032	0.08	0.0031	0.08	0.0037	0.09	0.0042	0.11	0.0040	0.10
K_2O	0.0016	0.02	0.0010	0.01	0.0011	0.01	0.0018	0.02	0.0013	0.01
Na_2O	0.0020	0.03	0.0015	0.02	0.0027	0.04	0.0016	0.03	0.0020	0.03
Total	0.0144	0.23	0.0150	0.26	0.0136	0.24	0.0180	0.33	0.0177	0.33
Total gain in 50 cm³.	0.0065	**0.10**	0.0150	**0.26**	0.0126	**0.22**	0.0150	**0.28**	0.0118	**0.28**

[a] In this table and in those following the figures given for millimols ferric and aluminum oxides express the number of divalent millimols to which the quantities of these bases found are equivalent, the millimol being the molecular weight taken in milligrams.

Fifty grams washed kaolin taken with 100 cm³ distilled water. Solution neutral to litmus. Found in 50 cm³ (as sulphates):[a]

Experiment with kaolin and water.

	Grams.	Millimols.
SiO_2	0.0006	....
CaO	0.0010	0.018
MgO	0.0005	0.013
K_2O	0.0002	0.002
Na_2O	0.0003	0.006
	0.0026	**0.039**

[a] Corrections have been applied to these figures for impurities in the barium hydroxide solution used as follows: MgO 0.0001, K_2O 0.0004, Na_2O 0.0006 gram.

Subtracting from the bases dissolved by copper sulphate solution that quantity which water alone takes up from the kaolin, 0.04 millimol, we have the following comparison of the copper precipitated and the bases replacing it:

Comparison of copper precipitated with bases dissolved.

	Millimols in 50 cm³.				
Original concentration	0.08	0.40	0.41	2.00	1.99
Copper precipitated	0.06	0.18	0.16	0.26	0.26
Bases dissolved, corr	0.06	0.22	0.18	0.24	0.24

The agreement is sufficient to show that the main reaction which takes place is an exchange of bases in equivalent quantities between the kaolin and the solution. Any adsorption that occurs is probably not over 0.02 millimol or 0.0013 gram copper, which in 25 grams kaolin is one in 20,000. In the case in which the bases are 0.04 millimol in excess the solution had unusual opportunity to dissolve material from glass, in which it stood for about five months.

Copper sulphate solution containing 2 millimols in 50 cm³ when filtered through 25 grams of kaolin in a column 1 cm. in diameter came through at first colorless and contained chiefly calcium sulphate.

The investigation of the action of kaolin was suggested by Kohler's paper on adsorption, to which reference has already been made.[a] The instances cited by Kohler of association of ore with kaolin while neighboring sandstone free from kaolin contains no metal seem attributable to chemical precipitation by residual silicate or aluminosilicate in the kaolin rather than to adsorption.

INFLUENCE OF SURFACE.

The surface exposed by a finely powdered mineral to the action of the salt solutions is of course very large, and it is only by multiplication of the reaction velocity in some such way that these changes become at all accessible to laboratory investigation. It may be remarked that fine grinding appears to be a less exceptionable means to this end than the use of high temperatures, which may give a very different result from that which would be obtained in a longer time at lower temperatures. The final equilibrium is not affected by fineness of division of the reacting solid. It is in general affected by a variation in temperature.

The surface actually exposed to a salt solution even in the case of a fresh rock in place is perhaps greater than is apparent. The permeability of such rocks was illustrated in the course of work with

[a] Zeitschr. prakt. Geol., vol. 11, 1903, p. 53.

selected cleavage fragments of very fresh orthoclase, which had lain for some months in a copper sulphate solution. In order to examine the surface of the feldspar the solution was poured off and the mineral very carefully and thoroughly washed with water and set aside to dry. Some days later minute crystals of copper sulphate were found on the surface of the mineral at points where no crack was visible to the eye. These were dissolved by soaking the fragments in water, and the surface was again thoroughly washed, with the same result at the end of a few days. Copper sulphate solution which had penetrated numberless interstices in the apparently unaltered mineral again came to the surface and deposited crystals. The washing was repeated many times with the same result.

That the extent to which silicate and solution exchange bases is dependent upon the surface exposed is evident from the following experiments, in which the amount of copper precipitated increases as the grinding is carried further.

Washed kaolin with cupric sulphate solution containing originally 0.1263 gram copper in 50 cm^3 precipitates 0.0165 gram copper. Agitating the mixture continuously for about two weeks increases the amount of copper precipitated to 0.0183 gram, and kaolin previously ground in the agate mortar precipitates under similar conditions as much as 0.0584 gram.

Orthoclase from San Diego County, Cal., ground for four hours, precipitated 0.0268 gram copper, while another portion of the same feldspar ground for about fifteen hours removed 0.0798 gram copper, other conditions being the same.

Orthoclase from Delaware County, Pa., precipitated 0.0469 gram copper; ground a few hours longer, 0.0656 gram; two portions of another sample, still more finely powdered, precipitated respectively 0.0728 gram after two days' contact and 0.0730 gram after twelve days.

ORTHOCLASE AND SALT SOLUTIONS.

The orthoclase used was in two lots of different fineness. Twenty-five grams of one lot precipitated from 50 cm^3 1 per cent cupric sulphate solution 0.0730 gram copper; of the other, 0.0469 gram. These numbers are in the ratio 1.554 : 1. The quantities of the various metals precipitated and bases dissolved are assembled in the following table. Twenty-five grams orthoclase and 50 cm^3 solution were used in each case. The results obtained with the coarser feldspar, indicated by *, have been multiplied by 1.554 and are what might be expected if feldspar of uniform fineness were used.

Summary of results with orthoclase and salt solutions.

Solution.	Metal precipitated.		Original content.	Bases dissolved.
	Grams.	*Milligram-atoms.*	*Milligram-atoms.*	*Millimols.*
* Magnesium sulphate	0.0099	0.40	1.98	0.47
* Calcium chloride	0.0207	0.51	2.44	0.54
* Manganous sulphate	0.0355	0.62	2.54	0.53
Ferrous sulphate	0.0365	0.65	2.10	....
Ferric sulphate	0.0648	1.16	1.21	1.41
* Nickelous sulphate	0.0549	0.93	2.06	0.92
Cupric chloride	0.0716	1.13	1.98	....
* Cupric nitrate	0.0625	0.98	1.99	1.01
Cupric sulphate	0.0729	1.03	1.98	0.85
Zinc sulphate	0.0611	0.93	3.05	0.99
* Strontium chloride	0.0427	0.48	2.32	0.51
Silver sulphate	0.1027	0.94	0.98	[a] 1.01
* Barium chloride	0.0982	0.71	2.04	0.78
* Auric chloride	0.0563	0.27	1.36	1.21
Lead nitrate	0.2970	1.43	2.00	1.14

[a] Milli-equivalents.

Owing to the fact that orthoclase gives up a perceptible quantity of alkali to water, the bases dissolved will be a few hundredths of a millimol in excess of the metal precipitated in those cases in which no basic salt is formed. Where the precipitate contains basic salt, the bases going into solution throw out more than their equivalent of metal. The auric chloride solution has, owing to acidity resulting from hydrolysis, dissolved bases in excess of the metal precipitated.

ORTHOCLASE AND CUPRIC SULPHATE.

Experiments.—Orthoclase A (from San Diego County, Cal.), containing 11.98 per cent K_2O, 3.32 per cent Na_2O; free from carbonates. In the first experiment the sample had been ground for four hours, in the second for fifteen hours. Contact was for one hour and overnight, respectively.

Experiments with orthoclase and cupric sulphate.

Constituent.	1.		2.	
	Grams.	Milli-mols.	Grams.	Milli-mols.
Copper in 50 cm^3:				
Originally	0.1262	1.98	0.1266	1.99
Finally	0.0994	1.56	0.0468	0.74
Loss	0.0268	0.42	0.0798	1.25
Content of 39.89 cm^3:				
CaO	....	....	0.0015	0.03
MgO	....	....	0.0018	0.05
K_2O	....	....	0.0348	0.37
Na_2O	....	....	0.0212	0.34
Total	....	....	0.0593	0.79
Content of 50 cm^3	....	....	0.0743	1.18

Orthoclase B (San Diego County, Cal.), containing 8.26 per cent K_2O, 4.38 per cent Na_2O, 0.03 per cent CO_2 (=0.0075 gram or 0.17 millimol CO_2 in 25 grams feldspar). In contact overnight with cupric sulphate solution.

Experiment with orthoclase and cupric sulphate.

Constituent.	Grams.	Millimols.
Copper in 50 cm³:		
Originally	0.1266	1.99
Finally	0.0685	1.08
Loss	0.0581	**0.91**
Content of 53.66 cm³ solution:		
K_2O	0.0356	0.37
Na_2O	0.0284	0.46
Total	0.0630	0.83
Content of 50 cm³	0.0587	**0.77**

Influence of concentration.—The influence of concentration of the cupric sulphate solution is foreshadowed by earlier work with other substances. The more concentrated the solution the greater the quantity of copper precipitated under similar conditions. Precipitation is not, however, proportional to concentration, but increases more slowly than the latter. In concentrated solutions a change in the concentration has comparatively little effect on the amount precipitated. A few determinations of the quantity of sulphate radical precipitated with the copper are appended. No definite relation appears between the two. In very dilute solution, where the copper is almost completely precipitated, the proportion of acid radical carried down decreases.

Experiments with orthoclase and cupric sulphate, showing influence of concentration.

Constituent.	Content in 50 cm³.									
	Grams.	Millimols.	Grams.	Millimols.	Grams.	Millimols.	Grams.	Millimols.	Grams.	Millimols.
Copper:										
Originally	0.0316	0.497	0.0632	0.994	[a]0.1263	1.99	1.487	23.39	2.978	46.82
Finally	Trace.	0	0.0215	0.338	0.0794	1.24	1.403	22.06	2.873	45.17
Loss	0.0316	0.497	0.0417	0.656	0.0469	0.75	[b]0.084	[c]1.33	[d]0.105	[e]1.65
Sulphate radical:										
Originally	0.0481	0.501	0.0961	1.001	......	......	......	......	......	......
Finally	0.0453	0.472	0.0870	0.906	......	......	......	......	......	......
Loss	0.0028	0.029	0.0091	0.095	......	......	......	......	......	......

[a] A solution of this original concentration treated with the same orthoclase, more finely ground, lost 1.03 mols copper and 0.176 mol SO_4; and with the orthoclase still more finely pulverized 1.15 mols copper and 0.182 mol SO_4.

[b] ± 0.002. [c] ± 0.02. [d] ± 0.003. [e] ± 0.05.

Influence of temperature.—The change in amount of precipitation caused by raising the temperature was found to be slight. Ortho-

clase with cupric sulphate heated for a few minutes on the water bath precipitated 0.082 gram copper as compared with 0.073 gram cold.

ORTHOCLASE WITH CUPRIC SULPHATE AND SULPHURIC ACID.

Twenty-five grams powdered orthoclase with 50 cm³ cupric sulphate solution and 0.7 cm³ 5.8 normal sulphuric acid (=2.03 millimols). Filtered after two days.

Experiment with orthoclase and cupric sulphate and sulphuric acid.

Constituent.	Grams.	Millimols.
Copper in 50.7 cm³:		
Originally	0.1263	1.99
Finally	0.1214	1.91
Loss	0.0049	0.08
Content of 40 cm³		
SiO_2	0.0122	....
Al_2O_3	0.0248	[a]0.73
CaO	0.0016	0.03
MgO	0.0019	0.05
K_2O	0.0635	0.68
Na_2O	0.0125	0.20
Total	0.1165	1.69
Content of 50.7 cm³	0.1477	2.14

[a] The alumina found is equivalent to 0.73 divalent millimol.

The bases dissolved are equivalent to the sulphuric acid present plus the copper precipitated. The orthoclase has therefore neutralized the dilute sulphuric acid solution (0.2 gram sulphuric acid in 50 cm³). The copper precipitated is but a small fraction of that precipitated from unacidified solution.

ORTHOCLASE AND CUPRIC NITRATE.

Filtered after two days.

Experiment with orthoclase and cupric nitrate.

Constituent.	Grams.	Millimols.
Copper in 50 cm³:		
Originally	0.1267	1.99
Finally	0.0865	1.36
Loss	0.0402	0.63
Content of 40 cm³:		
SiO_2	0.0027	....
Al_2O_3	0.0006	0.02
CaO	0.0006	0.01
MgO	0.0008	0.02
K_2O	0.0323	0.34
Na_2O	0.0080	0.13
Total	0.0450	0.52
Content of 50 cm³	0.0563	0.65

ORTHOCLASE AND CUPRIC CHLORIDE.

Filtered after three days.

Experiment with orthoclase and cupric chloride.

Constituent.	Grams.	Millimols.
Copper in 50 cm^3:		
Originally	0.1258	1.98
Finally	0.0542	0.85
Loss	0.0716	1.13

For comparison of the precipitation from sulphate, chloride, and nitrate of copper, see page 41.

ORTHOCLASE AND SILVER SULPHATE.

Twenty-five grams powdered orthoclase in contact for two days with 50 cm^3 silver sulphate solution: The silver was almost completely precipitated.

Experiment with orthoclase and silver sulphate.

Constituent.	Grams.	Milli-equivalents.
Silver in 50 cm^3:		
Originally	0.1066	0.98
Finally	0.0039	0.04
Loss	0.1027	**0.94**
Content of 30.27 cm^3:		
SiO_2, Fe_2O_3, etc	0.0007	....
CaO	0.0001	....
MgO	0.0004	0.02
K_2O	0.0170	0.36
Na_2O	0.0073	0.23
Total	0.0255	0.61
Total in 50 cm^3	0.0421	**1.01**

ORTHOCLASE AND LEAD NITRATE.

Twenty-five grams powdered orthoclase with 50 cm^3 lead nitrate solution. Filtered after five days.

Experiment with orthoclase and lead nitrate.

Constituent.	Grams.	Millimols.
Lead in 50 cm^3:		
Originally	0.4140	2.00
Finally	0.1170	0.57
Loss	0.2970	**1.48**
Content of 40 cm^3:		
SiO_2	0.0024	....
Al_2O_3, etc	0.0008	0.02
CaO	0.0017	0.03
MgO	0.0030?	0.07?
K_2O	0.0528	0.56
Na_2O	0.0143	0.23
Total	0.0750	0.91
Content of 50 cm^3	0.0938	**1.14**

ORTHOCLASE AND GOLD CHLORIDE.

Twenty-five grams powdered orthoclase with 50 cm^3 auric chloride solution ($AuCl_3$), which contained a slight excess of hydrochloric acid (0.03 millimol, determined by precipitation as silver chloride). The bases dissolved are in no apparent relation to the gold precipitated, being in very decided excess.

Experiment with orthoclase and gold chloride.

Constituent.	Grams.	Millimols.
Gold in 50 cm^3:		
Originally	0.2687	1.36
Finally	0.2325	1.18
Loss	0.0362	**0.18**
Content of 40 cm^3:		
SiO_2	Trace.	....
Fe_2O_3	Trace.	....
CaO	Trace.	....
MgO	0.0009	0.02
K_2O	0.0412	0.43
Na_2O	0.0103	0.17
Total	0.0524	0.62
Content of 50 cm^3	0.0655	**0.78**

Gold was not precipitated from hydroaurichloric acid ($HAuCl_4$) solution by orthoclase.

ORTHOCLASE AND ZINC SULPHATE.

Twenty-five grams powdered orthoclase with 50 cm^3 zinc sulphate solution. Filtered after two days.

Experiment with orthoclase and zinc sulphate.

Constituent.	Grams.	Millimols.
Zinc in 50 cm^3:		
Originally	0.1995	3.05
Finally	0.1384	2.12
Loss	0.0611	**0.93**
Content of 41.1 cm^3:		
SiO_2	0.0019	....
Fe_2O_3	0.0010	0.02
CaO	0.0014	0.03
MgO	0.0013	0.03
K_2O	0.0363	[a] 0.32
Na_2O	0.0127	[a] 0.41
Total	0.0546	[a] 0.81
Content of 50 cm^3	0.0665	[a] **0.99**

[a] The result for K_2O is low, that for Na_2O is high, and the totals are high.

KAOLIN AND ZINC SULPHATE.

Twenty-five grams kaolin in contact two days with 50 cm^3 of the same zinc sulphate solution precipitated 0.0169 gram (0.26 millimol) zinc.

ORTHOCLASE AND FERROUS SULPHATE.

Twenty-five grams orthoclase with 50 cm^3 ferrous sulphate solution in stoppered flask of some 200 cm^3 capacity. The air was not removed from the flask before stoppering. After two days the orthoclase, originally pure white, had taken on a light chocolate color, due to precipitated iron. Fifty cm^3 ferrous sulphate solution, similarly inclosed in a flask without orthoclase, showed no perceptible precipitate at the end of two days. The orthoclase, by rendering the solution alkaline, had accelerated oxidation and thus precipitation.

Experiment with orthoclase and ferrous sulphate: Iron in 50 cm^3.

	Grams.	Millimols.
Originally	0.1178	2.10
Finally	0.0813	1.45
Loss	0.0365	0.65

In a similar experiment in which some pains were taken to exclude air only 0.016 gram iron was precipitated.

KAOLIN AND FERROUS SULPHATE.

Twenty-five grams kaolin in presence of air with 50 cm^3 ferrous sulphate solution of about the same concentration as in the experiment with orthoclase removed approximately 0.015 gram (0.27 millimol) iron.

ORTHOCLASE AND FERRIC SULPHATE.

Twenty-five grams powdered orthoclase with 50 cm^3 ferric sulphate solution. Filtered after three weeks. But a trace of iron remained in the filtrate.

Experiment with orthoclase and ferric sulphate.

Constituent.	Grams.	Millimols.
Iron in 50 cm^3:		
Originally	0.0675	1.21
Finally	0.0027	0.05
Loss	0.0648	[a] **1.16**
Content of 40 cm^3:		
SiO_2	0.0067	.....
Al_2O_3	0.0114	0.34
CaO	0.0023	0.04
MgO	0.0012	0.03
K_2O	0.0519	0.55
Na_2O	0.0103	0.17
Total	0.0838	1.13
Content of 50 cm^3	0.1058	[b] **1.41**

[a] 3.48 milli-equivalents. [b] 2.82 milli-equivalents.

Barium sulphate obtained from 50 cm³ ferric sulphate solution after contact with orthoclase was 0.3528 gram, or 1.514 millimols; before contact (assumed equivalent to iron), 1.810 millimols. The loss of sulphate radical, 0.296 millimol, or 0.592 milli-equivalent, plus the gain in bases, 2.82 milli-equivalents, equals 3.412 milli-equivalents, practically identical with the loss of iron.

ORTHOCLASE AND MANGANOUS SULPHATE.

Twenty-five grams powdered orthoclase with 50 cm³ manganous sulphate solution. Filtered after two weeks.

Experiment with orthoclase and manganous sulphate.

Constituent.	Grams.	Millimols.
Manganese in 50 cm³:		
Originally	0.1397	2.54
Finally	0.1175	2.14
Loss	0.0222	0.40
Content of 40 cm³:		
SiO_2	0.0026	......
Al_2O_3, etc	0.0004	0.01
CaO	0.0012	0.02
MgO	0.0013	0.03
K_2O	0.0183	0.19
Na_2O	0.0013	0.02
Total	0.0251	0.27
Content of 50 cm³	0.0314	0.34

ORTHOCLASE AND NICKEL SULPHATE.

Twenty-five grams powdered orthoclase with 50 cm³ nickel sulphate solution. Filtered after two weeks' contact.

Experiment with orthoclase and nickel sulphate.

Constituent.	Grams.	Millimols.
Nickel in 50 cm³:		
Originally	0.1209	2.06
Finally	0.0856	1.46
Loss	0.0353	0.60
Content of 38.8 cm³:		
SiO_2	0.0031	......
Fe_2O_3, etc	0.0001	......
CaO	0.0008	0.01
MgO	0.0032	0.08
K_2O	0.0245	0.26
Na_2O	0.0069	0.11
Total	0.0386	0.46
Content of 50 cm³	0.0496	0.59

ORTHOCLASE AND MAGNESIUM SULPHATE.

Twenty-five grams powdered orthoclase with 50 cm³ magnesium sulphate solution.

Experiment with orthoclase and magnesium sulphate.

Constituent.	Grams.	Millimols.
Magnesium in 50 cm^3:		
Originally	0.0481	1.98
Finally	0.0417	1.71
Loss	0.0064	**0.26**
Content of 40 cm^3:		
SiO_2	0.0012	....
Al_2O_3, etc	0.0006	0.02
CaO	0.0016	0.03
K_2O	0.0118	0.12
Na_2O	0.0045	0.07
Total	0.0197	0.24
Content of 50 cm^3	0.0246	**0.30**

ORTHOCLASE AND CALCIUM CHLORIDE.

Twenty-five grams powdered orthoclase with 50 cm^3 calcium chloride solution. Filtered after five days.

Experiment with orthoclase and calcium chloride.

Constituent.	Grams.	Millimols.
Calcium in 50 cm^3:		
Originally	0.0977	2.44
Finally	0.0844	2.11
Loss	0.0133	**0.33**
Content of 40 cm^3:		
SiO_2, Al_2O_3, etc	0.0012	....
MgO	0.0004	0.01
K_2O	0.0179	0.19
Na_2O	0.0048	0.08
Total	0.0243	0.28
Content of 50 cm^3	0.0304	**0.35**

ORTHOCLASE AND STRONTIUM CHLORIDE.

Twenty-five grams powdered orthoclase with 50 cm^3 strontium chloride solution. Filtered after seven days.

Experiment with orthoclase and strontium chloride.

Constituent.	Grams.	Millimols.
Strontium in 50 cm^3:		
Originally	0.2032	2.32
Finally	0.1757	2.01
Loss	0.0275	**0.31**
Content of 40 cm^3:		
SiO_2	0.0007	....
Al_2O_3, etc	0.0004	0.01
CaO	0.0008	0.01
MgO	0.0005	0.01
K_2O	0.0157	0.17
Na_2O	0.0056	0.09
Total	0.0237	0.29
Content of 50 cm^3	0.0296	0.36
Subtract impurity in 50 cm^3 $SrCl_2$ solution	0.0017	0.03
	0.0279	**0.33**

ORTHOCLASE AND BARIUM CHLORIDE.

Twenty-five grams powdered orthoclase with 50 cm^3 barium chloride solution. Filtered after four days.

Experiment with orthoclase and barium chloride.

Constituent.	Grams.	Millimols.
Barium in 50 cm^3:		
Originally	0.2801	2.04
Finally	0.2169	1.58
Loss	0.0632	0.46
Content of 40 cm^3:		
SiO_2	0.0005	......
Al_2O_3, etc	0.0003	0.01
CaO	0.0010	0.02
MgO	0.0004	0.01
K_2O	0.0258	0.27
Na_2O	0.0054	0.09
Total	0.0334	0.40
Content of 50 cm^3	0.0418	0.50

A. S. Cushman has shown[a] that barium and aluminum are removed to some extent from solutions of their salts by a white china clay.

ORTHOCLASE AND POTASSIUM CHLORIDE.

Twenty-five grams powdered orthoclase with 50 cm^3 potassium chloride solution. Filtered after fourteen days. This orthoclase was of a different grinding from that used with other salts, and the precipitation of potassium given below is therefore not directly comparable with that of the other metals.

Experiment with orthoclase and potassium chloride.

Constituent.	Grams.	Milli-equivalents.
Potassium in 50 cm^3:		
Originally	0.1558	3.98
Finally	0.1443	3.69
Loss	0.0115	0.29
Content of 20 cm^3:		
SiO_2	0.0004	......
Al_2O_3, CaO	0.0002	......
MgO	0.0002	0.01
Na_2O	0.0086	0.14
Total	0.0094	0.15
Content of 50 cm^3	0.0235	0.37

[a] U. S. Dept. Agr., Bureau of Chem., Bull. 92, 1905, p. 18.

ORTHOCLASE AND SODIUM CHLORIDE.

Fifty cm^3 dilute (0.08N) sodium chloride solution after contact with 25 grams orthoclase contained about 35 milligrams K_2O as chloride.[a]

ORTHOCLASE AND SULPHURIC ACID.

Twenty-five grams powdered orthoclase with 50 cm^3 0.1 normal sulphuric acid (2.50 millimols).

Orthoclase and sulphuric acid: content of 40 cm^3.

Constituent.	Grams.	Millimols.
SiO_2	0.0242	
Al_2O_3	0.0313	[a] 0.92
CaO	Undet.	
MgO	0.0010	0.03
K_2O	0.0556	0.59
Na_2O	0.0108	0.17
Total	0.1229	1.71
Total in 50 cm^3	0.1536	2.14

[a] This is the number of divalent millimols to which 0.0313 gram alumina is equivalent.

The acid has dissolved somewhat less than its own equivalent of bases from the orthoclase. No change in the concentration of the sulphate radical could be detected. Barium sulphate obtained from 40 cm^3 before contact with orthoclase 0.4696 gram; after contact, 0.4698 gram. Precautions were taken to prevent the precipitation of alkali sulphate with the barium sulphate;[b] the chlorine carried down was determined and a correction made for it calculated to barium chloride.[c]

The relatively large amount of aluminum dissolved by an acid solution is noticeable as compared with the more nearly neutral salt solutions, which take chiefly the alkali metals from orthoclase. See the results with cupric sulphate in the presence of sulphuric acid and with ferric-sulphate solution, which is quite acid owing to hydrolysis. The salt solutions are similar in this respect to carbonic acid, which, according to Lemberg,[d] dissolves only the strong bases from silicates, while mineral acids dissolve all bases, including the sesquioxides.

[a] A. S. Cushman has very recently (U. S. Dept. Agr., Office of Public Roads Circular No. 38, 1906) described experiments showing that the amount of substance dissolved from orthoclase by ammonium chloride solution is decidedly greater than that dissolved by water.

[b] Hintz and Weber, Zeitsch. anal. Chem., vol. 45, 1906, p. 40; Lunge, G., Zeitsch. für angew. Chem., Heft. 12, 1905.

[c] Hulett, G. A., and Duschak, L. H., Zeits. für anorg. Chem., vol. 40, 1904, p. 196.

[d] Zeitsch. deutsch. geol. Gesell., vol. 28, 1876, p. 595.

ORTHOCLASE AND CARBONIC ACID.

Twenty grams orthoclase A taken with 50 cm^3 water, carbon dioxide passed through the mixture for twenty hours. The solution contained 0.040 gram of solid. Dilute cupric-sulphate solution dissolved about 0.065 gram from the same quantity of this orthoclase, and water less than 0.010 gram.[a]

MICROCLINE AND CUPRIC SULPHATE.

Twenty-five grams powdered microcline, $KAlSi_3O_8$, from Way's quarry, near Wilmington, Del., containing 0.03 per cent CO_2(= 0.0075 gram or 0.17 millimol carbon dioxide in 25 grams feldspar) with 50 cm^3 cupric sulphate solution containing 0.126 gram (2 millimols) copper. Filtered after twenty-four hours. The filtrate had lost approximately 0.100 gram (1.6 millimols) copper from 50 cm^3.

ALBITE AND CUPRIC SULPHATE.

Albite, $NaAlSi_3O_8$, containing 0.02 per cent CO_2 (=0.005 gram or 0.11 millimol CO_2 in 25 grams feldspar) in contact over night with cupric sulphate solution.

Experiment with albite and cupric sulphate.

Constituent.	Grams.	Millimols.
Copper in 50 cm^3:		
Originally	0.1266	1.99
Finally	0.0343	0.54
Loss	0.0923	1.45
Content of 38.34 cm^3:		
SiO_2	0.0046	....
Al_2O_3	0.0020	0.06
CaO	0.0107	0.19
Na_2O	[a]0.0516	0.83
Total	0.0689	1.08
Content of 50 cm^3.	0.0898	1.41

[a] Including a little MgO and K_2O.

The albite after this treatment was washed and dried (it had a bluish-green tinge) and again subjected to the action of cupric sulphate solution.

Copper found in 50 cm^3 of cupric sulphate solution with albite.

	Grams.	Millimols.
Originally	0.1263	1.99
Finally	0.0865	1.36
Loss	0.0398	0.63

[a] For the action of carbonic acid solution on various minerals see W. B. and R. E. Rogers, Am. Jour. Sci., 2d ser., vol. 5, 1848, p. 401, and R. Müller, Tschermaks Min. Pet. Mitt, 1877, p. 25.

ENSTATITE AND CUPRIC SULPHATE.

Twenty grams powdered enstatite (bronzite) $(MgFe)_2(SiO_3)_2$, from Webster, Jackson County, N. C., removed the color at once from 50 cm³ dilute cupric sulphate solution: 9 cm³ concentrated solution were then added, so that cupric sulphate was finally in excess.

Experiment with enstatite and cupric sulphate.

Constituent.	Grams.	Millimols.	Grams.	Millimols.
Copper in 59 cm³:				
Originally	0.6620	10.41	0.6620	10.41
Finally	0.2246	3.53	0.2274	3.58
Loss	0.4374	6.88	0.4346	6.83
Content of 40 cm³:				
SiO_2			0.0035	
Al_2O_3, etc			0.0003	0.01
CaO			0.0183	0.33
MgO			0.1159	2.85
K_2O			0.0007	0.01
Na_2O			0.0010	0.02
Total			0.1388	3.22
Content of 59 cm³			0.2052	4.76

In each of the experiments with enstatite the inner surface of the flask became coated with very fine grains which under the mircoscope appeared rounded. They were insoluble in water, soluble in dilute acid, and contained copper and sulphate, hence basic sulphate of copper.

AUGITE AND CUPRIC SULPHATE.

Augite, $Ca(Mg,Fe)Si_2O_6$, from Herschell Township, Hastings County, Ontario. Extracted with dilute hydrochloric acid before powdering. As used contained 0.28 per cent CO_2, = 0.07 gram or 1.59 millimols CO_2 in 25 grams augite. Twenty-five grams of the finely ground mineral removed the color completely from 50 cm³ dilute cupric sulphate solution: 4 cm³ of concentrated solution were added, and cupric sulphate was then in excess.

Experiment with augite and cupric sulphate.

Constituent.	Grams.	Millimols.
Copper in 54 cm³:		
Originally	[illegible]	6.83
Finally	[illegible]	1.39
Loss	[illegible]	5.45
Content of 52 cm³:		
SiO_2	[illegible]	
Al_2O_3	[illegible]	
CaO	[illegible]	0.59
MgO	[illegible]	1.[illegible]
K_2O / Na_2O	[illegible][a]	ca. 0.02
Total	[illegible]	[illegible]
Content of 54 cm³	[illegible]	2.51

a K_2SO_4 + Na_2SO_4 = [illegible] gram.

Here more SO_4 has left the solution than corresponds to the formula $Cu_4(OH)_3SO_4$. This was confirmed by a direct determination of SO_4 in an 8 cm^3 portion of the filtrate after removal of the copper. Barium sulphate obtained was 0.1688 gram, as against 0.2379 gram from the same volume originally, a loss of 0.0691 gram in 8 cm^3, equivalent to a loss of 2 millimols SO_4 from 54 cm^3.

Of the total copper precipitated, 5.45 millimols, about 2.12 millimols are accounted for by the carbonate present.

ANTHOPHYLLITE AND CUPRIC SULPHATE.

Twenty-five grams powdered anthophyllite $(Mg,Fe)SiO_3$, from Upper Providence, Delaware County, Pa., removed the copper completely from 50 cm^3 dilute cupric sulphate solution. Fifteen cm^3 concentrated solution was then added, so that cupric sulphate was finally in excess. Filtered after eleven days:

Experiment with anthophyllite and cupric sulphate.

Constituent.	Grams.	Millimols.
Copper in 65 cm^3:		
Originally	1.0194	16.02
Finally	0.3019	4.74
Loss	0.7175	11.28
Content of 50 cm^3:		
SiO_2	0.0104	....
Fe_2O_3, etc	0.0012	0.02
MnO,CaO	Trace.	....
MgO	0.2771	6.87
K_2O	0.0016	0.02
Na_2O	0.0041	0.07
Total	0.2944	6.98
Content of 65 cm^3	0.3827	9.07

AMPHIBOLE AND CUPRIC SULPHATE.

Twenty grams powdered amphibole, $Ca(Mg,Fe)_3(SiO_3)_4$, from St. Lawrence County, N. Y., removed the color completely from 40 cm^3 dilute cupric sulphate solution. In the first experiment impurities had been separated as far as possible from the amphibole, before fine grinding, by means of Thoulet solution; in the second such purification was not attempted. Filtered after twenty-four hours' contact.

Experiment with amphibole and cupric sulphate.

Constituent.	Grams.	Millimols.	Grams.	Millimols.
Copper in 40 cm^3:				
Originally	0.1015	1.60	0.1015	1.60
Finally	0	0	0	0
Loss	0.1015	**1.60**	0.1015	**1.60**
Content of filtrate:	24.4 cm^3		30 cm^3	
SiO_2	0.0009	....	0.0001	....
Fe_2O_3	0.0003	0.01	0.0006	0.02
CaO	0.0042	0.08	0.0089	0.16
MgO	0.0369	0.92	0.0471	1.17
K_2O	0.0049	0.05	0.0183	0.19
Na_2O	0.0089	0.14	0.0063	0.10
Total	0.0561	1.20	0.0813	1.64
Content of 40 cm^3	0.0920	**1.97**	0.1084	**2.19**

GARNET AND CUPRIC SULPHATE.

Twenty grams powdered garnet, $Ca_3Al_2Si_3O_{12}$, from Burke County, N. C., with 40 cm^3 dilute cupric sulphate solution. The garnet had been ground to about 100-mesh and separated from other minerals by means of Thoulet solution before it was finely pulverized. Filtered after three days.

Experiment with garnet and cupric sulphate.

Constituent.	Grams.	Millimols.
Copper in 40 cm^3:		
Originally	0.1010	1.59
Finally	0.0569	0.89
Loss	0.0441	**0.70**
Content of 35 cm^3:		
SiO_2	0.0037	....
Fe_2O_3	0.0012	0.02
MnO	0.0060	0.09
CaO	0.0016	0.03
MgO	0.0076	0.19
K_2O	0.0039	0.04
Na_2O	0.0011	0.02
Total	0.0251	0.39
Content of 40 cm^3	0.0287	**0.45**

OLIVINE AND CUPRIC SULPHATE.

Chrysolite (olivine) $(Mg,Fe)_2SiO_4$, from Webster, Jackson County, N. C., extracted with dilute hydrochloric acid before powdering. As used contains 0.32 per cent CO_2, equal to 0.08 gram or 1.82 millimols CO_2 in 25 grams. This amount of carbonate would precipitate about 2.43 millimols copper. Twenty-five grams olivine removed the color at once from 50 cm^3 dilute cupric sulphate solution; 4 cm^3 concentrated solution were added, so that cupric sulphate was finally in excess in the solution.

Experiment with olivine and cupric sulphate.

Constituent.	Grams.	Millimols.
Copper in 54 cm^3:		
Originally	0.4346	6.83
Finally	0.0842	1.32
Loss	0.3504	**5.51**
Content of 30 cm^3:		
SiO_2	0.0036	....
Al_2O_3	0.0004	0.01
CaO	0.0038	0.07
MgO	0.0954	2.36
K_2O	Trace.	....
Na_2O	Trace.	....
Total	0.1032	2.44
Content of 54 cm^3	0.1858	**4.40**

VESUVIANITE AND CUPRIC SULPHATE.

Twenty grams powdered vesuvianite, $Ca_6(Al,Fe)_3(OH,F)(SiO_4)_5$, from Sanford, Me., removed the color completely from 40 cm^3 dilute cupric sulphate solution. Filtered after two days' contact. Filtrate neutral or faintly alkaline to litmus.

Experiment with vesuvianite and cupric sulphate.

Constituent.	Grams.	Millimols.
Copper in 40 cm^3:		
Originally	0.1012	1.59
Finally	0	0
Loss	0.1012	**1.59**
Content of 30 cm^3:		
SiO_2	0.0001	....
Fe_2O_3, etc	0.0010	0.02
CaO	0.0505	0.90
MgO	0.0076	0.19
K_2O	0.0003	0.003
Na_2O	0.0009	0.02
Total	0.0604	1.13
Content of 40 cm^3	0.0805	**1.51**

EPIDOTE AND CUPRIC SULPHATE.

Twenty-five grams powdered epidote, $HCa_2(Al,Fe)_3Si_3O_{13}$, "from Germany," removed the color completely from 50 cm^3 dilute cupric sulphate solution; 5 cm^3 concentrated solution were afterwards added, so that copper sulphate was finally in excess in the solution. Filtered after nine days. Basic copper sulphate was deposited on the flask wall.

Experiment with epidote and cupric sulphate.

Constituent.	Grams.	Millimols.
Copper in 55 cm³:		
Originally	0.4238	6.67
Finally	0.0705	1.11
Loss	0.3533	5.56
Content of 40 cm³:		
SiO_2	0.0039	....
Fe_2O_3, etc.	0.0012	0.02
MnO	0.0046	0.06
CaO	0.0317	0.57
MgO	0.0177	0.44
K_2O	0.0017	0.02
Na_2O	0.0036	0.06
Total	0.0644	1.17
Content of 55 cm³	0.0886	1.61(?)

PREHNITE AND CUPRIC SULPHATE.

Twenty-five grams prehnite, $H_2Ca_2Al_2Si_3O_{12}$, from Upper Montclair, N. J., removed the color from 50 cm³ cupric sulphate solution containing 0.126 gram copper.

TOURMALINE AND CUPRIC SULPHATE.

Black tourmaline, Pierrepont, St. Lawrence County, N. Y.; 20 grams removed the color completely from 40 cm³ cupric sulphate solution containing 0.1 gram copper. Filtered after twenty-four hours. The filtrate was neutral to litmus and contained boron.

MUSCOVITE AND CUPRIC SULPHATE.

Twenty-five grams muscovite, $H_2KAl_3Si_3O_{12}$, from Jackson County, N. C., containing 0.026 per cent CO_2, equal to 0.0065 gram or 0.15 millimol CO_2 in the 25 grams, removed the color completely at once from 30 cm³ dilute cupric sulphate solution; 4 cm³ concentrated solution were added, furnishing an excess of cupric sulphate to the solution.

Experiment with muscovite and cupric sulphate.

Constituent.	Grams.	Millimols.
Copper in 34 cm³:		
Originally	0.4346	6.83
Finally	0.1632	2.56
Loss	0.2714	4.27
Content of 30 cm³:		
SiO_2, Al_2O_3, etc.	0.0039	....
CaO	[illegible]	0.02
MgO	0.0084	0.21
K_2O	[illegible]	1.28
Na_2O	0.0208	0.34
Total	[illegible]	1.85
Content of 34 cm³	[illegible]	[illegible]

BIOTITE AND CUPRIC SULPHATE.

Biotite, $(HK)_2(Mg,Fe)_2(Al,Fe)_2Si_3O_{12}$, from Rossie County, N. Y., containing 0.15 per cent CO_2, =0.038 gram or 0.86 millimol CO_2 in 25 grams biotite. Twenty-five grams removed the color at once from 50 cm^3 dilute cupric sulphate solution; 4 cm^3 concentrated solution were then added, making cupric sulphate in excess.

Experiment with biotite and cupric sulphate.

Constituent.	Grams.	Millimols.
Copper in 54 cm^3:		
Originally	0.4346	6.83
Finally	0.2246	3.53
Loss	0.2100	3.30
Content of 30 cm^3:		
SiO_2	0.0027	...
Al_2O_3, etc	0.0032	0.09
CaO	Tr.	...
MgO	0.0635	1.57
K_2O	0.0443	0.47
Na_2O	0.0046	0.07
Total	0.1183	2.20
Content of 54 cm^3	0.2129	3.96

The bases removed are here in excess of the copper precipitated, and it was found that water alone extracted a considerable quantity of material from the powdered mineral.

TALC AND CUPRIC SULPHATE.

Twenty grams powdered talc $(H_2Mg_3Si_4O_{12})$, from Harford County, Md., removed the copper almost completely from 40 cm^3 dilute cupric sulphate solution. Filtered after three days.

Experiment with talc and cupric sulphate.

Constituent.	Grams.	Millimols.
Copper in 40 cm^3:		
Originally	0.1010	1.59
Finally	[a] Tr.	Tr.
Loss	0.1	1.5
Content of 30 cm^3:		
SiO_2	0.0046	...
Al_2O_3, etc	0.0003	0.01
CaO	0.0018	0.03
MgO	0.0387	0.96
K_2O	0.0005	0.01
Na_2O	0.0005	0.01
Total	0.0464	1.02
Content of 40 cm^3	0.0619	1.36

[a] Ammonia gave slight blue color.

SHALE AND CUPRIC SULPHATE.

A shale from Newtown, Ariz. ("Morenci shale"), finely pulverized in an agate mortar and mixed with twice its weight of solution. The shale was made up chiefly of kaolin, glauconite, and epidote, and contained 6.74 per cent K_2O and 0.44 per cent Na_2O.

Experiments with shale and cupric sulphate.

COPPER IN 50 CUBIC CENTIMETERS.

	1.		2.		3.	
	Grams.	Millimols.	Grams.	Millimols.	Grams.	Millimols.
Originally	0.1277	2.01	0.1277	2.01	3.747	58.91
Finally	0.0063	0.10	0	0	3.584	56.35
Loss	0.1214	**1.91**	0.1277	**2.01**	0.163	**2.56**

CONTENTS OF FILTRATES.

Constituent.	80 cm³.		82.6 cm³.			
SiO_2	0.0053	....	0.0011	....	....	....
Al_2O_3, etc	0.0010	0.03	0.0036	0.12	....	....
CaO	0.0247	0.44	0.0185	0.33	....	....
MgO	0.0518	1.28	0.0754	1.88	....	....
K_2O	0.0840	0.89	0.0625	0.66	....	....
Na_2O	0.0035	0.06	0.0046	0.07	....	....
Total	0.1703	2.70	0.1657	3.06	....	....
Content of 50 cm³	0.1565	**1.69**	0.1003	**1.85**	....	....

Contact in the first experiment was for a few days, in the second for four months, and in the third for a few hours. The dilute solutions were neutral to litmus after contact with the shale.

The microscopic examination was made by Mr. W. Lindgren of the Geological Survey, at whose suggestion the action of the shale toward cupric sulphate solution was examined. The chemical analysis was by Dr. W. F. Hillebrand, of the Geological Survey. The occurrence of cuprite in this shale is common at Morenci.[a]

CLAY GOUGE WITH CUPRIC SULPHATE.

Clay gouge vein-filling from Silver Plume, Colo. Contains 3.92 per cent CO_2 (=0.784 gram or 17.84 millimols in 20 grams), largely as ferrous carbonate; 3.52 per cent K_2O, 0.18 per cent Na_2O. Ground in agate mortar. Twenty grams taken with 40 cm³ concentrated cupric sulphate solution. Filtered after three days.

Experiment with clay gouge and cupric sulphate.

Constituent.	Grams.	Millimols.
Copper in 40 cm³:		
Originally	2.382	3.75
Finally	2.091	3.29
Loss	0.291	**0.46**

[a] See Lindgren, Prof. Paper U. S. Geol. Survey, No. 43, p. 191.

The bases dissolved from the gouge were chiefly alumina and potash. The ferrous carbonate appears to have taken little if any part in the precipitation of the copper, in contrast with the action of the more soluble calcium carbonate, which is completely dissolved by cupric sulphate solution (see p. 84).

CLAY GOUGE WITH SILVER SULPHATE.

Twenty grams of the finely ground material taken with 40 cm^3 silver sulphate solution. Filtered after four days.

Experiment with clay gouge and silver sulphate.

Constituent.	Grams.	Millimols.
Silver in 40 cm^3:		
Originally	0.0844	0.78
Finally	Tr.	Tr.
Loss	0.084	0.78
Content of 25 cm^3:		
SiO_2	0.0012	
Al_2O_3	0.0002	
CaO	0.0013	0.02
MgO	0.0026	0.06
K_2O	0.0222	0.24
Na_2O	0.0016	0.03
Total	0.0291	0.35
Content of 40 cm^3	0.0466	0.56

The filtrate gave no reaction for ferric salt with potassium sulphocyanate nor for ferrous with ferricyanide. Again the ferrous carbonate apparently had not been affected.

Work with this material was made possible through the kindness of Mr. G. H. Garrey, who placed samples at the writer's disposal.

CALCITE (ICELAND SPAR) AND CUPRIC SULPHATE.

0.0502 gram (= 0.502 millimol) calcite in contact with 50 cm^3 dilute cupric sulphate solution. Filtered after two days.

Calcite and cupric sulphate: content of 50 cm^3.

Constituent.	Grams.	Millimols.
Copper:		
Originally	0.1263	1.986
Finally	0.0820	1.289
Loss	0.0443	0.697
$BaSO_4$:		
Originally	0.4674	2.002
Finally	0.4284	1.835
Loss	0.0390	0.167

The loss of copper is to the loss of sulphate as 4:0.96, indicating the precipitation of a basic sulphate similar in composition to brochantite

and langite. This is in accordance with the work of Becquerel.[a] The precipitate contained no calcium. Brochantite varies in composition from $CuSO_4,5/2CuO,3H_2O$ to $CuSO_4,7/2CuO,aq$. Moissan, Traité, 5,83.

FLUORITE AND CUPRIC SULPHATE.

Fluorite removed practically no copper at all from dilute cupric sulphate solution.

PYRITE AND CUPRIC SULPHATE.

Ground pyrite (25 grams) washed with sulphuric acid, alcohol, and ether removed 0.0286 gram copper from 50 cm^3 cupric sulphate solution containing originally 0.1263 gram copper.

GLASS AND CUPRIC SULPHATE.

One hundred cm^3 1 per cent cupric sulphate solution in contact ten days with 71 grams coarsely powdered window glass.

Glass and cupric sulphate: content of 50 cm^3.

Constituent.	Grams.	Millimols.
Copper in 50 cm^3:		
Originally	0.1271	2.00
Finally	0.1200	1.89
Loss	0.0071	0.11
SiO_2	0.0070	0.000
CaO	0.0029	0.052
MgO	0.0001	0.002
K_2O	0.0006	0.007
Na_2O	0.0026	0.042
Total	0.0132	0.103

The glass, after washing with water until the washings no longer contained copper, retained a green color, unmistakable on comparison with the original glass. Extraction with hydrochloric acid gave a solution from which 0.0056 gram copper and 0.0057 gram barium sulphate were obtained, i. e., $4Cu:1.1SO_4$.

An accumulation of sediment in the stock bottle of 1 per cent cupric sulphate solution gave 0.0083 gram copper and 0.0084 gram barium sulphate, again $4Cu:1.1SO_4$. Contact with a silicate precipitates in these cases, therefore, the same basic sulphate which results on treating cupric sulphate solution with insufficient alkali for complete precipitation.

POSSIBLE APPLICATION TO GEOLOGIC PHENOMENA.

What part these reactions have actually played in ore deposition and other geologic changes is for the geologist to decide. Lindgren[b]

[a] Comptes rendus, vol. 34, 1852, p. 573.

[b] Copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 119.

has recently noted the fact that the basic copper sulphate, brochantite, whose composition is that of one of the substances formed by the action of silicates on copper-salt solutions, is an ore of more frequent occurrence than is usually supposed, it having been confounded in many cases with chrysocolla or malachite. The sulphide ores could readily result from such basic compounds through reduction of the sulphate by organic matter or by other oxidizable substances. The change from the cupric to the more commonly found cuprous compounds, such as cuprite and chalcocite, could be due to the same reducing agents or even to hydrogen sulphide. Cuprous sulphide appears to be more stable than cupric sulphide at high temperatures, and it may well be more stable at lower temperatures also. A cupric salt precipitated by hydrogen sulphide under ordinary conditions forms some cuprous sulphide—for example, $2CuSO_4 + 2H_2S = Cu_2S + S + 2H_2SO_4$, in addition to the cupric sulphide which makes up the main mass of the precipitate, that is, $CuSO_4 + H_2S = CuS + H_2SO_4$.

As illustrating further the reducibility of cupric compounds by hydrogen sulphide, cupric sulphide when dissolved in hydrochloric acid forms cuprous chloride—$2CuS + 2HCl = 2CuCl + H_2S + S$. This reaction is mentioned by Gmelin-Kraut[a] and has been confirmed by the writer.

FORM OF PRECIPITATION.

The immediate condition in which the metal is thrown down from the solution by a silicate is perhaps of secondary importance, subject as the newly formed substance is to spontaneous change into a more stable form, as from amorphous or colloidal to crystalline in structure, and also to the modifying and transforming influence of continually renewed portions of active solutions. The fact of prime significance geologically seems to be that by a process of simple chemical exchange the metal may be removed from solution and fixed in the solid state and thus concentrated, by contact with even the most stable of the silicates.

The changes under consideration involve the action of the alkali or alkaline-earth salt of a weak acid (silicic or alumino-silicic) and are thus analogous to the more familiar behavior of sodium carbonate with solutions of salts of the metals. Owing to hydrolysis the precipitates caused by sodium carbonate tend to split up into the acid and base (carbonic acid and metal oxide or hydroxide) and the weaker the base the more marked is this action. The precipitate from solutions of salts of strong bases, such as calcium chloride, is the normal carbonate; a weaker base, such as nickel, is precipitated as basic carbonate or a mixture of the normal carbonate with hydroxide or oxide; while the very weak bases, as iron in ferric salts, are precipi-

[a] Handbuch, 6th ed., vol. 3, p. 620.

tated as hydroxide or oxide containing little or no carbonate, and the corresponding quantity of carbon dioxide is set free:

$$CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl;$$
$$2NiCl_2 + 2Na_2CO_3 + H_2O = NiCO_3, Ni(OH)_2 + CO_2 + 4NaCl;$$
$$2FeCl_3 + 3Na_2CO_3 + 3H_2O = 2Fe(OH)_3 + 3CO_2 + 6NaCl.$$

The action of a silicate may be expected to be similar to that of the carbonate, with the difference that the silicate, as the salt of a weaker acid than carbonic, will tend to produce a more basic precipitate—that is, one containing more hydroxide.

The hydroxide of the metal, with more or less silicate and an amount of silica corresponding to the quantity of precipitated hydroxide, will therefore make up the precipitate in case the solution and the precipitant come together under such conditions that the metal is completely precipitated. When insufficient alkali for complete precipitation is added to a metal salt solution the resulting precipitate is in some cases a basic salt where with excess of alkali it would be a hydroxide. Cupric sulphate, for instance, with alkali in excess gives $CuSO_4 + 2KOH = Cu(OH)_2 + K_2SO_4$; but where the copper salt is in excess the result is $4CuSO_4 + 6KOH = Cu_4(OH)_6SO_4 + 3K_2SO_4$. The same basic salt is formed by calcium carbonate or by such silicates as glass, acting on excess of cupric sulphate solution. There seems to be, therefore, reason to expect that in the precipitations with which we are here concerned the same basic salt will play an important part. As a matter of fact, in the cases of enstatite and epidote contact with cupric sulphate caused the formation of a coating on the flask wall which contained copper and sulphate and was insoluble in water, and was therefore basic copper sulphate. After filtration of shale from cupric sulphate solution a similar precipitate formed.

That the silicate of the metal is actually formed to some extent when orthoclase, for instance, is brought into contact with metal salt solutions is evident in the case of the sodium salt, where precipitation as hydroxide is out of the question. The experiment shows also that although barium is precipitated (50 cm^3 solution lose 0.0802 gram $= 0.58$ millimol barium) the resulting solution remains neutral to litmus and hence contains practically no barium hydroxide whatever. Barium has therefore not been precipitated from this solution in the form of hydroxide, for this would necessitate the formation of a saturated solution of that compound. The conclusion seems inevitable that the barium which has left the solution is in combination as a silicate.

Further evidence that the silicate of the precipitated metal is formed is found in the fact that the reverse reactions can be made to take place, while the precipitation of hydroxide or basic sulphate of copper is under these conditions practically an irreversible reaction. Orthoclase treated with cupric sulphate solution gives up potassium

for copper, which is precipitated. The resulting slightly green powder, washed until water extracts at most a minute trace of copper, if treated with potassium sulphate solution gives up copper in considerable quantity, thus reversing the first reaction. Precipitated cupric hydroxide or basic sulphate similarly treated with potassium sulphate solution gives up no copper. The following are the experimental data on this point:

The copper is not extracted from the orthoclase by water: 50 cm^3 water stirred up with 25 grams of washed and air-dried orthoclase which had taken 0.073 gram copper from solution dissolved a scarcely weighable trace (about 0.05 milligram) of the metal.

The copper is extracted by potassium sulphate solution: After washing, as just described, and freeing from water by suction 50 cm^3 potassium sulphate solution of normal concentration were stirred up with the orthoclase and the solution was then filtered. Fifty cm^3 filtrate now contained 0.008 gram copper.

Copper is not extracted from cupric hydroxide or basic cupric sulphate by potassium sulphate solution: Fifty cm^3 cupric sulphate solution (0.127 gram copper) was precipitated with sodium hydroxide, and after thorough washing neither water nor potassium sulphate solution dissolved copper from the precipitate. About one gram basic cupric sulphate was prepared by treating cupric sulphate with insufficient sodium hydroxide for complete precipitation. After thorough washing water still dissolved a trace of copper from the product. The solubility in potassium sulphate solution was not appreciably greater.

Another sample of orthoclase treated as above described gave a similar result. Several successive extractions with potassium sulphate solution yielded decreasing quantities of copper. Anthophyllite after contact with cupric sulphate and washing gave only a trace of copper when extracted with water. Fifty cm^3 potassium sulphate solution, however, removed about 0.006 gram copper. Vesuvianite which had been treated with cupric sulphate solution of such dilution that the copper was completely precipitated gave up no copper on extraction with potassium sulphate solution, owing probably to the precipitation of the copper entirely as hydroxide where the precipitant is in excess, as it was in this case.

Van Bemmelen[a] shows that salts which are not removed from a colloid by water may be dissolved by means of another salt solution. Calcium chloride, for instance, in a well-washed preparation of chromic hydroxide, was taken out by a concentrated solution of potassium sulphate. There is no reason to believe that the copper extracted from orthoclase and other silicates, as just described, was in a condition similar to that of the calcium chloride in Van Bemmelen's experiment.

[a] Jour. prakt. Chem., vol. 23, 1881, p. 387.

SUMMARY.

The natural silicates precipitate the metals from solutions of salts, while at the same time the bases of the silicates are dissolved in quantities nearly equivalent to the precipitated metals. The bases most commonly replacing the metals in these processes are potassium, sodium, magnesium, and calcium. Where exact equivalence is wanting, it is attributable either to solubility of the mineral in pure water or to the precipitation of basic salts.

The metals are precipitated as hydroxides or basic salts (in the case of cupric sulphate, for instance, as a basic cupric sulphate similar to brochantite or langite) with more or less metal silicate.

The specific materials on which work was done are albite, amphibole, augite, biotite, enstatite, garnet, clay gouge, kaolin, microcline, muscovite, olivine, orthoclase (3), prehnite, shale, talc, tourmaline, and vesuvianite, with cupric sulphate solution; and orthoclase with salts of sodium, potassium, magnesium, calcium, strontium, barium, manganese, iron, nickel, copper, zinc, silver, gold, and lead. Experiments were also made on the action of kaolin on solutions of salts of zinc and iron, and of glass, fluorite, and pyrite on cupric sulphate and of carbonic and sulphuric acids on orthoclase.

Adsorption, a mechanical surface attraction, plays a comparatively insignificant part, if any, in the retention of copper by kaolin. If adsorption is lacking in the case of kaolin, it seems reasonable to assume that it is lacking in the case of other silicates also.

Under the conditions of the experiments described the precipitation of copper caused by orthoclase does not differ materially in quantity from that caused by pyrites.

A dilute salt solution decomposes orthoclase and dissolves its constituents to about the same extent as does a saturated solution of carbonic acid. Both are much more efficient in this respect than water.

Orthoclase (and presumably other alkali silicates also) accelerates the oxidation of ferrous sulphate by the oxygen of the air. A similar influence may be expected in other oxidation reactions that take place more readily in the presence of alkali than in the presence of acid.

It is worthy of note that the iron of ferrous silicates is not found in solution replacing copper after the precipitation of the latter. This was also true of the iron in a clay gouge containing considerable ferrous carbonate.

The writer wishes to acknowledge gratefully suggestions and assistance from various geologists of the Survey, especially from Mr. W. H. Weed and Mr. Waldemar Lindgren. He is also under obligation to Prof. G. P. Merrill and Mr. Wirt Tassin, of the National Museum, and others for minerals furnished.

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[Bulletin No. 312.]

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THE GRANITES OF MAINE

BY

T. NELSON DALE

WITH AN INTRODUCTION BY

GEORGE OTIS SMITH

PREPARED IN COOPERATION WITH THE MAINE STATE SURVEY COMMISSION

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ILLUSTRATIONS.

INTRODUCTION—THE OCCURRENCE OF GRANITE IN MAINE.

By George Otis Smith.

GEOGRAPHIC DISTRIBUTION.

Areally, granite is perhaps the most important rock in Maine. Slates, schists, sandstones, and limestones of various types occur in the different sections of the State, but the mountains and hills of the interior and the islands and headlands of the coast for the most part all exhibit slopes and cliffs of massive granite. Even where the exposures are of other rock varieties the notable abundance of granite dikes and quartz veins indicates the presence of granite at no great distance. Not only is this rock most conspicuous, but its importance in both the geology and the industry of the State can hardly be overestimated.

The areal distribution of the granite is somewhat irregular, as may be noted on the map accompanying this report (Pl. I). Three general granitic regions may be distinguished for convenience of description—that of the western tier of counties, that of the eastern part of the State, and the Mount Katahdin area, in the north-central portion of the State. In addition to these larger districts there should also be mentioned three small areas in Lincoln, Kennebec, and Somerset counties, which are intermediate in position between the three main regions.

The granitic areas of the western group are not widely separated, and the largest of these areas as outlined on the map is not all granite, although, as will be explained in a later paragraph, the intrusive granite forms the larger part of the rock exposed within these limits. The northernmost of these granite masses is exposed in the elevated country which forms the divide between the Chaudiere drainage on the Canadian side of the international boundary and the headwaters of Androscoggin and Dead rivers in the northern part of Franklin County. South of this is a much larger area of granite, extending from the western part of Somerset County across Franklin into Oxford County and including prominent peaks, like Mount Bigelow and Saddleback Mountain, as well as the rugged country south of the Rangeley Lakes.

South of this is a large, irregular-shaped area of metamorphic rocks—gneisses and schists—more or less thoroughly impregnated

with granite, which extends southward and eastward through seven counties, reaching the coast at Casco Bay on the west and Penobscot Bay on the east. Southwest of this area is a mass of granite, which constitutes the eastern extension of the White Mountain massif of New Hampshire and reaches the coast at Casco Bay, Cape Porpoise, and York Cliffs.

The Mount Katahdin granite lies wholly within the forested region of northern Maine, and therefore its exact boundaries are unknown. At the northeastern end of the area is the highest elevation in the State, Katahdin, 5,268 feet above the sea, a typical granite mountain. To the southwest, possibly connected with this area, is the granite near Lake Onawa, where the rock is well exposed in a deep cut of the Canadian Pacific Railroad.

In the eastern counties three extensive granitic areas may be distinguished. Of these the northernmost extends southwestward from New Brunswick across the northern portions of Washington and Hancock counties into Penobscot, and almost wholly is forested country. Southeast of this is the horseshoe-shaped granitic area of Hancock County, which crosses into Washington County near Cherryfield. On the west the outlying Mount Waldo mass may represent an extension of the same granite, although connecting exposures along the Penobscot River below Bucksport have not yet been observed. In the Hancock County area the granite can be traced from the shore of Eggemoggin Reach northward along a line of prominent hills, which are best seen from the Maine Central Railroad near Green Lake. North of Aurora these granite hills have less relief, but east of that place the belt extends southward with increasing ruggedness of topography, Tunk Mountain, near the Washington County Railroad, being characteristic of this southern portion.

The other occurrence of granite in eastern Maine is the belt extending from New Brunswick across the St. Croix, then southwestward to the coast at Addison, and thence along the coast to Penobscot Bay. Within this belt are included several large islands—Swans, Deer, and Vinalhaven—and the mountains of Mount Desert owe their topographic prominence to the massive character of the granite composing them.

Of the smaller areas of granite not included within the three groups described above, that in Lincoln County comprises the town of Waldoboro and islands at the head of Muscongus Bay. The Hallowell-Augusta area in Kennebec, the North Jay and Phillips area in Franklin, and the Hartland and Norridgewock areas in Somerset County represent the larger of many small intrusive masses of granite in central Maine. With these should be mentioned the granite occurrence in Aroostook County, about 12 miles west of Houlton.

In the preparation of the map (Pl. I), showing the distribution of

the granite, as described above, the data used have been largely the results of areal mapping, for folio publication, by E. S. Bastin, C. W. Brown, and the writer, and of general reconnaissance by the writer, assisted by Mr. Bastin. In the more northern areas the work by H. E. Gregory and the earlier mapping by C. T. Jackson and C. H. Hitchcock have been utilized to supplement this recent work. Mr. Brown also contributed the results of recent observations in the vicinity of Mount Katahdin.

GEOLOGIC RELATIONS.

Wherever the granites of Maine have been studied in any degree of detail, their relations are plainly those of intrusion into part, at least, of the adjacent formations. Evidence that the granite is the younger rock is found in the tendency shown by some of the granite areas (see Pl. I) toward elongation in a northeast-southwest direction, parallel to the general trend of the main structural features of the region, but more conclusive evidence is found in the fact that the granite actually cuts across the bedding of the sedimentary rocks and has in some localities produced in them a very considerable amount of alteration. Bordering the granite in Franklin County, for example, and in some other parts of the State, are andalusite schists which plainly represent sedimentary strata metamorphosed by the granite. In many regions, as will be described later, the granite masses are bordered by gneisses which are formed by a lit-par-lit injection of sedimentary schists by granitic material. Thus the general relations throughout the State point to the granites being relatively the younger rocks.

The feature which is perhaps the most significant in the geologic relations of the granites to the other rocks of the State is the great contrast between the sharpness of certain granite borders and the indefinite character of others. In the vicinity of Bluehill and Brooksville, for example, in Hancock County, the contact is absolutely sharp, pure granite being succeeded within a foot by schists unmixed with granite. Along such sharp borders, too, the granite usually preserves its normal texture up to the very contact, and the surrounding rocks show almost no effects of contact metamorphism. In striking contrast to this are the broad contact zones which characterize most of the granite masses lying farther westward. In the Rockland region, for example, the Sprucehead–Clark Island granite area is bordered on the northwest by a zone, 3 to 4 miles in width, in which sedimentary slates and schists are intimately associated with injection gneisses, basic granites, fine-grained granite, pegmatite, diorite, gabbro, and diabase. These igneous rocks were plainly derived from the granitic magma and are most abundant in those portions of the contact zone which lie nearest to the areas of pure granite. A granite area near South Penobscot, in Hancock County,

is almost completely surrounded by a border zone, from one-fourth mile to 1½ miles in width, in which the rocks are largely diorite and gabbro with small amounts of igneous gneiss and fine-grained granite.

Some hint as to the cause of this contrast in the character of granite borders in different regions is obtained from a study of the rocks in the southwestern part of the State, especially in Sagadahoc, Cumberland, and Oxford counties and the southern part of Kennebec County. Here, as indicated on the map (Pl. I), there are considerable areas from which large continuous masses of normal granite are absent, but in which the prevailing sedimentary schists have been intruded in the most intimate manner by dikelike or irregular masses of pegmatite and fine-grained granite, and in many places have been given a gneissic texture by the lit-par-lit injection of granitic material. The intruded and injected areas pass gradually into the larger areas of nearly pure normal-textured granite shown on the map. To explain such intimate injection and intrusion in areas far removed from any outcropping masses of pure normal granite it seems necessary to assume that a granite mass underlies these rocks at no great distance below the present surface and that such injected areas constitute in reality portions of the "roof" of great granite batholiths.

It seems almost certain that the escape of gases and water vapor and the differentiation of basic rocks from the granitic magma would proceed much more rapidly from the upper surface of a buried magma than from its sides. It is to be expected, therefore, that portions of the "roof" of such granite masses should be particularly characterized by the abundance of pegmatites, diorite, gabbro, etc., and by notable contact metamorphism of the sedimentary rocks through which these forced their way. The sharpness of other granite contacts is readily explained by supposing that they represent the side contacts of the granite batholiths, where the gases and water vapors escaped from the magma laterally in much less volume and where the accompanying metamorphic effects were very much less than at the upper surface.

The geologic history of the great granite intrusions of Maine may be summarized, therefore, as follows:

All of the granite masses now exposed solidified below the surface as it existed at the time they were intruded. The depth at which they solidified varied in different places. Erosion gradually removed the rocks covering some of the masses and has in some places even revealed their deeper portions, so as to show the sharp lateral contacts. In other places all or a part of the "roof" of the granite masses still remains. The present land surface, therefore, truncates the various granite batholiths at different horizons. It is highly probable that a further erosion of 500 to 1,000 feet would expose much larger areas of granite than now appear.

All of the granites of Maine are believed to belong to the same great period of igneous activity. This conclusion is based on (1) their general lithologic similarity, the differences between granites of different areas being no greater than those observed between different parts of a single area; (2) the nearly continuous extension of certain granite belts for long distances, notably the belt which extends with slight interruptions from New Brunswick to Jonesport and thence to Mount Desert, Deer Isle, Vinalhaven, and Tenants Harbor; (3) the fact that certain areas of granite are connected by belts that are intensely intruded with granitic rocks, thus suggesting that the granite areas may be continuous beneath the present surface; (4) the fact that most of the granites of the other New England States appear to be of about the same age as those of Maine, thus suggesting a single period of great igneous intrusion throughout the whole New England province.

There can be little doubt at least of the contemporaneity of the granite of the Perry basin, on the eastern border of Maine, with that of Vinalhaven, since the granite forms a practically continuous belt between these two localities, and relations are shown in these two regions which approximately fix the age of the granite. In the Silurian rocks of the Perry region no granite pebbles are found, but such pebbles, plainly derived from the main granite masses of this region, occur abundantly in the conglomerate at the base of the Perry formation, which is of late Devonian age. The granite of the Perry region is therefore late Silurian or Devonian in age. Evidence confirmatory, but less complete, is found in the Vinalhaven region, where the granites intrude surface volcanics of Niagaran age.

SCOPE OF THIS REPORT.

This investigation was undertaken at the request of the Maine State Survey Commission, which cooperated with the United States Geological Survey in meeting the expenses of the field work. The plan of this study of the Maine granites provided for both the scientific and the economic phases of the subject, and it is believed that the author has succeeded in making this report an important contribution along both these lines.

Discussion of the granites and associated rocks from a purely petrologic standpoint has been omitted, and no chemical tests have been made except as the chemical composition is believed to affect the durability of the stone. The observations on the relation of the bands of knots to flow structure in the granite, on the parallelism of banding with sheeting and rift, on the relation of sheeting to the surface of the rock, on the cause of the sheeting, and on the spacing and distribution of joints furnish data of high scientific value, which can be used by the geologist interested in the physics of intrusion. Several

of these same observations can be utilized by the quarry superintendents also. For example, the value of a quarry site is largely dependent on the joint system, and an understanding of the distribution of knots or other imperfections in the stone will guide quarry operations. The discussion of the cause of the discoloration termed " sap " also has a practical value, as well as the suggestion as to the use that can be made of granite so discolored.

The arrangement of the data presented in this report is believed to favor its use by all classes of readers. The broader facts of the classification and description of the Maine granites are separated from the local details of individual quarries. The endeavor has been to present all the essential facts relating to the granites of Maine, so that the report will be of value to geological students as well as to architects, contractors, and quarry owners. It is the plan to follow this publication with similar bulletins by the same author describing the granites of other parts of New England, so that together these will furnish an authoritative report on the granite of this area, which produces over 60 per cent of the granite output of the country.

IMPORTANCE OF THE INDUSTRY.

The statistics of production given on pages 183–184 of this report indicate the valuation that should be placed upon the granite industry of Maine. In a single county the product of the granite quarries annually reaches the value of $1,000,000. For the whole State the output for 1905 exceeded that for any previous year, its value reaching nearly $2,750,000.

Vermont and Massachusetts are the only other States whose granite production approaches that of Maine. Both of these, as well as several other States, lead Maine in the value of monumental granite produced, so it is on the output of building stone that the preeminence of Maine depends. The value of Maine granite quarried in 1905 for building purposes was over $2,000,000, while in the item of dressed granite of this character the production was valued at $1,648,687, or nearly one-third of the output of the whole country. The next most important product of the Maine granite quarries is paving blocks, the amount being over one-seventh of that of the United States, and exceeded only by the output of Wisconsin.

As is shown in this report, the basis of Maine's granite industry is largely the position of quarry sites at tide water. This accessibility of granite of the best grade makes it possible for the Maine product to be an important factor in the markets for building material in the cities of the Atlantic seaboard. Some quarries, both on the coast and inland, furnish building stone and monumental granite of such quality that their product is in special demand. With these advantages the granite industry in Maine deserves consideration as one of the more important assets of the State.

THE GRANITES OF MAINE.

By T. Nelson Dale.

INTRODUCTION.

The success of an industry that deals directly with any natural material must involve sooner or later, at some point, a knowledge of the laws pertaining to that material. Moreover, persons engaged in such an industry are led by their very occupation to seek, with an interest that is in proportion to their intelligence, an explanation of the phenomena that daily come before them. For these reasons it has been the writer's aim to make the following report both economic and scientific. Indeed, its scientific part forms to a large extent the basis of its economic part. In the scientific discussion the presentation is succinct. Details that are of interest to the scientific specialist alone have been omitted or very briefly summarized, and technical terms have been, as far as possible, avoided. Such scientific terms as have been necessarily used are explained in the glossary at the end of the report, where, also, some of the quarrymen's terms are given and translated for the benefit of the general reader.

For the general geological knowledge that underlies this report the writer is indebted to a considerable body of scientific literature. The works of Archibald Geikie, G. P. Merrill, Julien, A. Rosiwal, Buckley, and Watson have been carefully consulted. Other authorities for particular facts or theories will be named at the proper places. The design is to present the subject in the light of present science and in simple form.

The material for the local details and descriptions given in this report was collected in three months in 1905, during which time the writer visited 129 quarries and prospects. Although the complexity of the subject would have justified more extended research at the quarries, it was for several reasons impracticable to extend the season's field work.

Mr. Albert Johannsen, of the United States Geological Survey, has verified or corrected the writer's microscopic determinations of

53 thin sections of typical rocks for this report; Mr. E. C. Sullivan, of the Survey, has made 10 determinations of carbonate in granite, and Mr. W. T. Schaller, also of the Survey, has determined 2 minerals. Mr. Wirt Tassin, assistant curator of the National Museum, has made an analysis and report on a new mineral from a quartz vein, and Dr. George P. Merrill, head curator of geology of the same institution, has determined a feldspar from the Waldoboro quarry. Mr. G. K. Gilbert, geologist of the United States Geological Survey, has contributed an important photograph (Pl. VII, *A*), bearing upon origin of sheet structure in granite, with an explanatory note. Prof. James F. Kemp, of Columbia University, has kindly made some bibliographical contributions. The statistical table of granite production in Maine was prepared by Miss Altha T. Coons, of the Survey.

The word "granites," in the title, is used primarily in its popular and commercial sense, and includes also the so-called "black granites." The proper scientific names of the rocks thus designated are given in the sections devoted to classification and to the descriptions of the quarries and their products.

PART I.—SCIENTIFIC DISCUSSION.

GRANITE PROPER.

GRANITE IN GENERAL.

DEFINITION.

Granite, in a general sense, is essentially an entirely crystalline igneous rock, consisting mainly of quartz, potash feldspar, and a feldspar containing both soda and lime, also of a small amount of either white or black mica or both, and sometimes of hornblende, more rarely of augite, or both. Where granite has, subsequent to its crystallization, been subjected to pressure sufficient to produce a parallelism in the arrangement of its minerals—that is, a schistosity—it is no longer a true granite, but a gneiss or granitoid gneiss.

ORIGIN.

Granite is now regarded as the product of the slow cooling and crystallization of molten glasslike matter at a dull-red heat—matter which contained superheated water, and was intruded from below into an overlying mass of rock of sufficient thickness not only to prevent its rapid cooling and its general extrusion at the surface, but also to resist its pressure by its own cohesion and powerfully to compress it by its own gravity. As carbonic acid can be liquefied only under pressure, its presence in liquid form within some of the micro-

scopic cavities in the quartz of granite is alone evidence that the rock was formed under pressure. The amount of contraction that this inclosed liquid has suffered in cooling has afforded a basis for estimating not only the amount of heat under which the rock began to form, but also the pressure under which it solidified. That the temperature at which granite solidified was comparatively low has been inferred from the fact that it contains minerals which lose their physical properties at temperatures higher than dull-red heat. The relations of the mineral constituents of granite to one another show the order in which they must have crystallized. This order differs from that in which they would crystallize if molten in a dry state, but laboratory experiments have shown that the presence of even a small quantity of water suffices to change that order of crystallization. The presence of superheated water in the formation of granite, inferred from the arrangement of its minerals, and the pressure indicated from a study of the vacuities in the microscopic cavities of its quartz show that the conditions requisite to its formation included not only the pressure of a great overlying mass of rock but also powerful expansive pressure from below. Had this molten matter been extruded at the surface it would have cooled so rapidly that but few of its constituent molecules would have had time to arrange themselves in geometric order. The process of crystallization would have been arrested by the sudden passage of the material into the solid state, and the product would have been a volcanic glass somewhat resembling that which forms cliffs in Yellowstone National Park. In granite, however, the mass has cooled slowly enough to permit the complete crystallization of the originally molten glass-like matter, and no unarranged molecules remain.

The overlying rock mass which furnished so large a part of the pressure required to form granite has at many places been removed from it by erosive processes that operated through great stretches of time. Indeed, it is only by the removal of this mass that granite is anywhere naturally exposed. Although this mass may have measured thousands of feet in thickness, its former presence is at some places attested only by a thin capping on the granite or by fragments which the lacerating action of the intruding granite has incorporated into itself. A remnant of this capping occurs at the Waldoboro quarry and an inclusion of it at the Freeport quarry. (See Pls. IX, *A;* VII, *B.*)

The lacerating effect of an intrusive eruption and the subsequent erosion of some of the overlying strata have been reproduced experimentally.[a] The conversion of granite itself back into a material which upon cooling under ordinary conditions has proved to be a

[a] Howe, Ernest, Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 294–296, Pl. XLIII.

glass, has been effected in the laboratory, and the chief mineral constituents of granite have been artificially crystallized at high temperature in the presence of water vapor under high pressure, but the conditions requisite for the production of a granitic rock from its chemical constituents have not yet been successfully imitated.

Some granite shows locally a certain alignment of its mica plates and feldspars, due to the flow of the mass while it was in a plastic state—a structure which was probably controlled by the pressure and form of the bordering rock. This "flow structure" should not be confounded with the schistosity which is due to later pressure and which also involves mineral changes and is usually regional rather than local in extent.

The great differences in the grade of texture in granites—the mineral particles ranging from an average diameter of one-fiftieth inch (0.50 mm.) and even 0.0069 inch (0.175 mm.) to over half an inch—is attributed to differences in the rate of cooling. The portions at the margin of the mass, which cooled rather quickly, crystallized in very small crystals, while the central portions, which cooled more gradually, became coarsely crystalline.

MINERALOGICAL COMPOSITION.

Feldspar is the most conspicuous and generally the most abundant mineral in granite. By its color or colors it usually determines to a large extent the general color of the rock; and by the light which it reflects it causes also its brilliancy. It is easily distinguished from the other constituents by its smooth cleavage surfaces and milky, bluish white, or opalescent, or reddish, brownish, or greenish color. Granite usually contains two kinds of feldspar, the most abundant of which is generally potash feldspar, a silicate of alumina and potash. This occurs in one of two crystal forms, orthoclase or microcline, or in both, which, however, can be distinguished only by means of the microscope. The other feldspar (plagioclase), containing both soda and lime, although it may be of the same color as the potash feldspar, can often be distinguished from it by the very fine parallel lines on its surface. Usually it differs greatly in color from the first. The potash feldspar may be reddish or brownish; the plagioclase may be white or greenish. Under the microscope the soda-lime feldspar can be readily distinguished from the potash feldspar by its behavior in polarized light, which brings out its crystalline structure and indicates its particular variety and approximate chemical composition. A granitic rock that contains the two feldspars in equal proportions is distinguished by a special technical name.

Quartz (silica), the next most abundant constituent, is readily known by its glassy luster, uneven fracture, and brittleness. It may

be colorless, bluish, opalescent or amethystine, or smoky. The quartz in the rock determines in some measure its shade. The vitreousness of the quartz greatly affects the granite.

The next most abundant constituent of granite is mica, which is present in two forms—the white (muscovite, or potash mica), essentially a silicate of alumina with potash, soda, and ferrous oxide, and the black (biotite, or magnesia mica), essentially a silicate of alumina with potash, magnesia, and both ferric and ferrous oxide. Granite may contain one or both of these. The dimensions and number of the scales of black mica largely determine the shade of many granites.

Hornblende, a constituent of many granites, although greenish (rarely bluish), may appear as dark as the black mica, but, unlike that mineral, it does not split into scales. Augite and hornblende resemble each other so closely when in minute particles that they can be distinguished only by means of the microscope. Both may occur.

In addition to these more important minerals, others are usually present in minute or microscopic quantities. Some of these, kaolin, sericite (a potash mica or muscovite), chlorite, epidote, zoisite, and calcite, as well as paragonite (soda mica), which may possibly be present, are the result of chemical changes in the feldspars or the biotite or hornblende and are therefore called "secondary." Others—like zircon, apatite, titanite, rutile, tourmaline, fluorite, garnet, magnetite, molybdenite, ilmenite, pyrite, allanite—are regarded as original "accessory constituents." Calcite also occurs in microscopic quantity as an original mineral of some granites.[a] Of these minor accessories, pyrite (iron disulphide) and calcite (lime carbonate) alone have economic significance, for these may discolor or weaken the stone when dissolved or oxidized on an exposed surface. Ten Maine granites were tested for calcite by Mr. Eugene C. Sullivan at the laboratory of the United States Geological Survey in May, 1906. Under treatment with warm dilute acetic acid they yielded percentages of CaO (lime), from a trace up to 0.24. They also showed from 0.014 to 0.218 per cent of CO_2 (carbonic acid). Seven of them showed some MgO (magnesia), two of them showed CO_2 in excess of amount required to form $CaCO_3$ (lime carbonate). The calculated result shows the presence of from 0.14 to 0.43 per cent of $CaCO_3$ (lime carbonate), and two of them show from 0.06 to 0.08 per cent of $MgCO_3$ (magnesia carbonate). Mr. Sullivan writes that "the lime extracted by acetic acid is in nearly every case in excess of that required to form calcium carbonate with the carbon dioxide found. This would indicate that lime and magnesia are present in some easily soluble form,

[a] See Zirkel, Petrographie, vol. 2, p. 13, and Weinschenk, Abhandl. Math.-phys. Classe k. Bayer. Akad., vol. 18, p. 730, Pl. V.

besides the carbonate. It is probably safe to assume that the acetic acid has not attacked the biotite."

During the preparation of this report the accessory minerals garnet, zircon, titanite, magnetite, pyrite, apatite, and molybdenite have been found in Maine granites. Allanite also is reported.

A white silicate which occurs in the Waldoboro granite in isolated more or less incomplete crystals, some of them as much as half an inch in diameter, and which becomes slightly yellowish on weathering, has been determined by Dr. George P. Merrill, of the United States National Museum, as a feldspar between oligoclase and albite. The feldspar of that granite is, however, oligoclase.

The arrangement of the important minerals in the stone will be described under the heading "Texture."

The percentages of the mineral constituents differ within wide limits in granites from different localities. The percentage of muscovite and of the ferromagnesian minerals (biotite, hornblende, augite) is always small, while that of the feldspar and quartz is large. There is considerable variation in the relative amounts of feldspar and quartz and still more in the amounts of each of the feldspars.

The reddish color of the feldspar—a color that plays an important part in the appearance of the stone—is due to an amount of ferrous oxide which rarely exceeds 1 per cent of the mineral and which under the highest powers of the microscope shows no definite form.

CHEMICAL COMPOSITION.

The chemical composition of granite is of less scientific and economic significance than its mineral composition, for, although chemical analysis shows the percentages of the constituent elements, the process by which these are determined necessarily mingles the elements of several minerals whose proportions vary and whose contribution to the physical properties of the rock differ greatly. When, however, a combination of elements occurs only in one or two of the minerals the chemical analysis serves to corroborate the evidence obtained by microscopic analysis.

Many analyses of granite have been published, but it will suffice here to give the extremes of the percentages shown by some of the more important of these and to refer the reader to works containing complete analyses.[a] Four analyses of granites from Scotland, Ireland, Italy, and Sweden show the following ranges:[b]

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[a] See Washington, H. S., Prof. Papers U. S. Geol. Survey Nos. 14, 1903, and 28, 1904; also Clarke, F. W., Bull. U. S. Geol. Survey No. 228, 1904.

[b] Geikie, Archibald, Text-book of Geology, 4th ed., vol. 1, London, 1903, p. 207.

Analyses of European granites.

SiO_2 (silica)	70.60–74.82
Al_2O_3 (alumina)	14.86–16.40
Fe_2O_3 (ferric oxide)	0.10– 1.63
FeO (ferrous oxide)	0.36– 1.64
MnO (manganese oxide)	0.00– 0.48
MgO (magnesia)	0.23– 1.00
CaO (lime)	0.89– 2.47
Na_2O (soda)	3.51– 6.12
K_2O (potash)	3.55– 5.10

Ten analyses, made at the laboratory of the United States Geological Survey, of granites from Arizona, California (2), Colorado (4), Maryland, Michigan, and Montana, show the following ranges:[a]

Analyses of American granites.

SiO_2 (silica)	66.68–77.68
Al_2O_3 (alumina)	11.63–16.38
Fe_2O_3 (ferric oxide)	0.00– 1.66
FeO (ferrous oxide)	0.09– 3.32
MgO (magnesia)	0.04– 2.19
CaO (lime)	0.12– 4.89
Na_2O (soda)	2.36– 5.16
K_2O (potash)	1.87– 6.50
TiO_2 (titanium dioxide)	0.07– 0.45
P_2O_5 (phosphoric acid)	Trace– 0.10

The average of 21 analyses of even-grained Georgia granites made by Watson[b] yield the following percentages:

Analyses of Georgia granites.

SiO_2 (silica)	[c] 69.97
Al_2O_3 (alumina)	16.63
Fe_2O_3 (ferric oxide)	1.28
CaO (lime)	2.13
MgO (magnesia)	0.55
Na_2O (soda)	4.73
K_2O (potash)	4.71

It should be noted that in all these analyses most of the lime is to be attributed to the lime-soda feldspar and nearly all the rest of it to apatite (lime phosphate).

It is of interest to note in this connection that certain Scotch and Irish granites contain from 1.6 to 2.8 volumes of gas per volume of rock. This gas is inclosed in microscopic cavities within the minerals, and in the Scotch granite consists of carbon, oxygen,

[a] See Bull. U. S. Geol. Survey No. 228, p. 54, analysis D; p. 197, analysis D; p. 231, analysis A; p. 232, analysis A; p. 185, analysis B; p. 161, analyses A, C, F; p. 78, analysis A; p. 145, analysis C.

[b] Watson, Thomas L., Bull. Georgia Geol. Survey No. 9-A, 1902, p. 241.

[c] Extremes 68.38–72.56.

hydrogen, and nitrogen in the following combinations and proportions: CO_2, 23.60; CO, 6.45; CH_4, 3.02; N_2, 5.13; H_2, 61.68.[a] These gases are probably present in all granites.

TEXTURE.

Definition.—By the texture of a rock is to be understood those characteristics which are apparent on its surface, or, more exactly, the forms and mutual relations of its minerals as seen without and with a microscope.

Character and grade.—The most important feature of granite is the character of its grain. Some granites are even grained; others contain more or less thinly disseminated and complete crystals of feldspar in a mass of finer, even-grained material—that is, they show what is called porphyritic texture. The next most important feature—perhaps more important—is the relative coarseness or fineness of grain in an even-grained granite. Three grades of texture of this sort may be distinguished: (1) *Coarse*, in which the feldspars generally measure over 1 cm., or two-fifths inch; (2) *medium*, in which they measure under 1 cm. (two-fifths inch) and over 0.5 cm. (one-fifth inch); (3) *fine*, in which they measure under 0.5 cm. (one-fifth inch). In some coarse-grained granites the feldspars measure one or several inches, and in some fine-grained ones all the particles range from 0.25 mm. to 1 mm. (one twenty-fifth inch) in diameter, and some average as low as 0.50 mm., or one-fiftieth inch. Extremely fine ones average 0.175 mm., or about seven one-thousandths inch.

Forms of minerals.—Even without the aid of the microscope it will be noticed that, except in granites of porphyritic texture, the minerals rarely attain their complete crystalline form. They have interfered with one another's growth. It will also be noticed that some of the crystals of feldspar in some granites are surrounded by a border of a different feldspar. Thus a red feldspar may be bordered by a white or greenish one, or vice versa. Either of these may be the potash feldspar and the other a soda-lime feldspar. It will also be noticed that many of the feldspars are not simple incomplete or complete crystals, but "twins," having the cleavage planes in one half at a different angle from those in the other half, so that when held in the sunlight only one half will reflect the light in one position.

Arrangement of minerals.—A polished surface of any medium or coarse-grained granite shows that the quartz fills up the spaces between the feldspars—that is, was formed after them—also that both feldspars and quartz inclose particles of mica, etc., which must therefore have crystallized before them. Under the microscope the arrangement of the minerals is found to be such that they must

[a] Tilden, W. H., Proc. Roy. Soc. London, vol. 60, No. 366, Feb. 20, 1897, pp. 454, 455.

usually have crystallized in the following order: Magnetite, pyrite, apatite, zircon, titanite, hornblende, biotite, muscovite, the feldspars, and, last of all, the quartz. It should be noted, however, that many of the feldspar crystals contain intergrown quartz, so that some of the quartz must therefore have crystallized at the same time as the feldspar. The structure of the potash feldspar in some granites is very intricate, as it contains microscopic intergrowths of a lime-soda feldspar, both having evidently crystallized at the same time or in close alternation. Also, as stated above, the potash feldspar may be rimmed with soda-lime feldspar, or vice versa.

PHYSICAL PROPERTIES.

Granite derives its physical properties from its mineralogical constitution, particularly from its large content of feldspar and quartz, and from its texture. Among these physical properties the most important are weight, cohesiveness, elasticity, flexibility, hardness, expansibility, porosity, and vitreousness. Each of these qualities will be taken up in the order in which they are here stated.

Weight.—In order to establish a fixed standard the weight of a rock is compared to that of an equal volume of distilled water. The weight thus determined is called its specific gravity. The specific gravity of granite ranges from 2.593 to 2.731. The average of these extremes is 2.662, which is equivalent to 2 long tons, or 4,480 pounds, to the cubic yard, or about 165 pounds to the cubic foot. Geikie[a] calls attention to the change in the weight of granite when immersed in sea water, as given by Stevenson.[b] A red granite having a specific gravity of 2.71, or 13.2 cubic feet to the ton in air, will in sea water of a specific gravity of 1.028 measure 21.30 cubic feet to the ton.

Cohesiveness.—The amount of cohesiveness of a rock is ascertained by determining its crushing strength—that is, the weight in pounds required to crush it or to destroy its cohesion. The ultimate compressive strength of granite ranges from about 15,000 to 43,973 pounds per square inch,[c] but the usual range is from 18,000 to 34,000 pounds. Herrmann[d] gives the crushing strength of European granites as ranging from 1,100 to over 3,000 kilograms per square centimeter.

Elasticity.—Tests made at the United States Arsenal at Watertown, Mass., to determine the compressive elasticity of specimens of granite from Arkansas, Connecticut, Maine, Minnesota, and New

[a] Text-book of Geology, 4th ed., p. 568.
[b] Stevenson, T., Harbours, p. 107.
[c] These extremes are from Wisconsin granites. See Buckley, Ernest B., on the building and ornamental stones of Wisconsin: Bull. Wisconsin Geol. and Nat. Hist. Survey, No. 4, pp. 361, 390.
[d] Herrmann, O., Steinbruchindustrie und Steinbruchgeologie, p. 43.

Hampshire, show that specimens of granite, in a gaged length of 20 inches and a diameter of 5.5 inches at the middle, when placed under a load of 5,000 pounds to the square inch, suffered compression ranging from 0.0108 to 0.0245 inch, resulting in a lateral expansion ranging from 0.005 to 0.007 inch, and giving ratios of lateral expansion to longitudinal compression ranging from 1:8 to 1:47.[a]

Flexibility.—Although granite contains a large amount of brittle material (estimated at from 30 to 60 per cent) and the interlocking of its various particles give to it great cohesion and rigidity, yet in sheets of sufficient thinness and areal extent it is flexible. Sheets half an inch thick and 4 feet long may be bent, as noted in the description of the Lawton quarry, at Norridgewock, page 151. Whether flexibility in this case was conditioned upon a slight loosening of the grains by chemical and physical change is uncertain.

Hardness.—As will be seen by reference to the tests for hardness described on page 64, granites differ greatly in hardness. This difference is due not merely to differences in the percentage of quartz, but also to variations in the character of the feldspars.

Expansibility.—The expansibility of granite has been variously tested. Bartlett[b] found that a piece of granite coping 5 feet long, under the effect of a winter temperature of 0° F. and a summer temperature of 96° F., expanded 0.027792 inch, or 0.000004825 inch per inch for each degree. The Ordnance Department at the Watertown Arsenal[c] tested the granites referred to under the heading "Elasticity," and found that slabs of gaged lengths of 20 inches in passing from a cold-water bath at 32° F. through a hot-water bath at 212° F., and back again to cold water at 32° F., expanded from 0.0017 to 0.0059 inch, averaging 0.0040 inch.

Porosity.—Granite contains and absorbs water, which is held in microscopic spaces both within and between its constituent minerals. Ansted[d] states that granite generally contains about 0.8 per cent of water and is capable of absorbing about 0.2 per cent more. In other words, a cubic yard of granite weighing 2 tons contains in its ordinary state about 3½ gallons of water and can absorb nearly a gallon more on being placed in pure water for a short period. Buckley[e] found that the pore space or porosity in fourteen Wisconsin granites ranges from 0.17 to 0.392 per cent, and that the ratio of absorption (percentage of weight of absorbed water to the average dry weight of the sample) of the same granites ranges from 0.17 to 0.50. Mer-

[a] Report of the tests of metals, etc., made with the United States testing machine at Watertown Arsenal, Mass. (1895), 1896, pp. 339–348.

[b] Bartlett, Wm. C., Experiments on the expansion and contraction of building stones by variation of temperature: Am. Jour. Sci., 1st ser., vol. 22, 1832, pp. 136–140.

[c] Op. cit., p. 322.

[d] Ansted, D. T., quoted by Edward Hull in A treatise on building and ornamental stones of Great Britain and foreign countries, 1872, p. 30.

[e] Op. cit., p. 400.

rill[a] has shown that certain Maryland granites absorb from 0.196 to 0.258 per cent of water after drying 24 hours at 212° F. and then being immersed for 24 hours.

Vitreousness.—The vitreousness of granite is due to that of its contained quartz. Under extreme changes of temperature, as in a city fire, where water is thrown on the stone, granite exfoliates badly. This exfoliation or shelling is attributable to the unequal expansion or contraction of its outer and its inner portions under sudden changes of temperature. It is also probably connected with the vitreousness of the quartz and possibly also in a measure with the liquids contained in microscopic cavities of the quartz. The unequal expansive ratios of the different constituent minerals would result in general disintegration, not in exfoliation.

Buckley[b] subjected 2-inch cubes of five Wisconsin granites to high temperature tests and found that they were all destroyed at 1,500° F. One of them cracked at 1,000°; two others began to disintegrate at 1,200°. The most notable change was that "when struck with a hammer or scratched with a knife they emitted the sound peculiar to a burnt brick." Cutting[c] applied a fire test to granites from eighteen quarries in Maine, Maryland, Massachusetts, Minnesota, New Hampshire, Vermont, and Virginia, with the result that after saturation they all stood a temperature of 500° F. without damage, but showed the first appearance of injury at 700°–800° and were rendered worthless at 900°–1,000°. Twenty-three sandstones subjected to the same tests showed the first appearance of injury at 800°–900° and became worthless at 950°–1,200°. His general results agree with those of experience as to the relative fire endurance of granite and sandstone.[d] The behavior of granite under very high temperature is not attributable to any one physical property. The physical properties of granite are further discussed in Part II, under the heading "Tests of granite" (pp. 63–66).

CLASSIFICATION.

The varieties of granite are so numerous that for either scientific or economic purposes they need to be classified.

Scientific classification.—For scientific purposes granites may be classified according to their less essential mineral constituents—mica, hornblende, and augite. Thus a granite containing white mica is termed a muscovite granite; one containing black mica, a biotite granite; one containing both, a muscovite-biotite granite. A granite

[a] Merrill, G. P., Maryland Geol. Survey, vol. 2, pp. 94, 95.

[b] Op. cit., p. 411.

[c] Cutting, Hiram A., Sixth Rept. Agric. Vermont, 1880, pp. 47–54; also, Durability of building stone: Am. Jour. Sci., 3d ser., vol. 21, 1881, p. 410.

[d] Merrill, G. P., Stones for building and decoration, p. 435.

containing black mica and hornblende is called a biotite-hornblende granite. Granites may also be classified according to both their mineral and their chemical composition. These two form the basis of the latest classification of igneous rocks, which is too complex to be outlined here.[a]

Economic classification.—For economic purposes granites may be classified first as to *texture*—as even grained, or porphyritic, or as coarse, medium, or fine, according to the scale given on page 20. Those of extra coarse or extra fine texture can be distinguished by the prefix *very*. This scale gives five grades of texture. Granites should also be classified as to *general color and shade*—as pinkish, reddish, lavender, or gray or warm gray (that is, a gray showing the presence of a slight reddish, reddish-purplish, or yellowish tinge), and as dark, medium, or light. They may be further classified and designated by *the colors of their most conspicuous minerals*, the feldspars, quartz, and mica. A stone may thus be called a coarse, even-grained, warm-gray granite, with lavender and white feldspars, smoky quartz, and black mica; or another may be called a fine, even-grained, very light gray granite, with white feldspar, clear quartz, and both white and black mica. This scheme of classification will suffice for general economic purposes. The outline of a complete economic description of granite can be constructed from the tests enumerated in Part II, on pages 63–66.

MAINE GRANITES.

CLASSIFICATION.

The granites exposed at the Maine quarries fall naturally into six groups:

1. *Biotite granite*, consisting of the two feldspars, quartz, and black mica.

2. *Muscovite-biotite or biotite-muscovite granite*, with both black and white mica, the name of the predominating mica being in each case the first.

3. *Hornblende-biotite or biotite-hornblende granite*, with hornblende and black mica, named according to the predominance of one or the other of these minerals.

4. *Quartz monzonite*, in which the amount of lime-soda feldspar is so large as to about equal that of the potash feldspar. The monzonites quarried in Maine contain biotite or biotite and hornblende.

5. *Hornblende granite*, consisting of the feldspars, quartz, and hornblende.

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[a] See Cross, Iddings, Pirrson, Washington, Quantitative Classification of Igneous Rocks based on Chemical and Mineral Characters, with a Systematic Nomenclature, Chicago, 1903; also Jour. Geology, vol. 10, 1902, pp. 555 et seq.

6. *Quartz diorite*, used for building purposes and not classed commercially as "black granite." This contains only lime-soda feldspar, with quartz, hornblende, and biotite.

The first three groups include nearly all the granite quarried in the State. Quartz monzonite is quarried at Sprucehead, Knox County, and at Norridgewock, Somerset County; hornblende granite is quarried in a small way on Mount Desert Island, and quartz diorite is quarried at Bryant Pond, Oxford County, and has been quarried at Hartland, Somerset County, and for local use at Alfred, York County.

The general appearance and petrographic peculiarities of the stone at each quarry will be briefly stated in Part II, in the descriptions of the quarries and their products, and a classification of Maine granites based upon economic principles will be found on pages 72–75.

Maine granites as exposed at the quarries show a wide range of texture. Some are porphyritic, others even grained, ranging from very fine, in which the size of the particles averages about one-fiftieth inch (one-half millimeter) to very coarse, in which the feldspars measure an inch or more in diameter. They exhibit also considerable variety of color—pinkish, reddish, gray of various shades, and light lavender. The differences in the color of the two feldspars and the variations in the amount of biotite and in the size of its scales produce more or less marked contrasts of color and of shade. The quartz also, if smoky, darkens the general color, and if clear, lightens it.

GENERAL STRUCTURE.

The term "structure" embraces all the divisional planes that traverse the rock. These occur at intervals ranging from a microscopic distance to one measured by scores of feet, and either cross or, very rarely, give a course to the texture resulting from crystallization.

FLOW STRUCTURE.

At some of the quarries (as Dodlin Hill, near Norridgewock, and Clinton Sherwood quarry, on Crotch Island) two varieties of granite lie in contact, the dividing line between them being vertical (see p. 109 and figs. 18 and 32 for details). One of the granites at Dodlin Hill also shows a light and dark vertical banding. The direction of the flow of the granite at these quarries must therefore have been vertical. At the Mount Waldo quarry, near Frankfort (see p. 154), vertical flow structure also occurs. At Tayntor & Company's quarry, near Hallowell (see p. 120), a faint vertical banding is visible in one of the walls, and a thin section of the rock shows a parallelism of the biotite. The same parallelism is seen also at an old quarry near Brunswick (see p. 76). The arrangement of the mica in the granite at both places was doubtless governed by the direction of the flow of

the material prior to its crystallization. At one of the North Jay quarries (see p. 82) a similar parallelism in the mica occurs, but its course is in horizontal waves 20 feet wide and 3 feet high; while at another of these quarries similar waves pitch 10°–40°. At the Pownal Granite Company's quarry, in Pownal (see p. 79), the rock shows a parallelism of the minerals, the planes of structure dipping 10°, and a thin section of the granite does not show any bending of the mica plates or straining of the quartz particles.

In some of the Massachusetts and New Hampshire quarries the writer found flow structure parallel to the surface of the granite at its contact with the overlying rock and also surrounding and parallel to the surface of large blocks of other rock included with the granite. (See "Inclusions," p. 52.)

The very local character of these structural features indicates that they are not due to pressure which affected the entire region, but that they originated while the granitic masses were still plastic, for they conform to the general direction of the flow or to some local modification of it. A granite that exhibits flow structure is by some writers called a flow gneiss. The courses of the lines of this flow structure in the Maine quarries, when the bands are vertical, are N. 35° W., N. 20° W., and N. 45° E.

RIFT AND GRAIN.

The rift in granite is a feature of considerable scientific interest and of much economic importance. It is an obscure microscopic foliation—either vertical, or very nearly so, or horizontal—along which the granite splits more easily than in any other direction. The grain is a foliation in a direction at right angles to this, along which the rock splits with a facility second only to that of the fracture along the rift. After a little experience an observer can detect the rift with the unaided eye, where it is marked. The only available data on this subject are furnished by Tarr and Whittle.[a]

Tarr presents four figures reproduced from drawings made from enlarged views of thin sections showing the rift in Cape Ann hornblende-biotite granite. These figures and his descriptions indicate that rift consists of microscopic faults, most of which meander across feldspar and quartz alike, although some go around the quartz particles rather than through them. In the feldspars rift usually follows the cleavage. These minute faults are lined with microscopic fragments of the mineral they traverse and some of them send off short, minute diagonal fractures on either side. In examining such

[a] Tarr, R. S., The phenomena of rifting in granite: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 267–272, figs. 1–4; also Economic Geology of the United States, 1895, p. 124. Whittle, Charles L., Rifting and grain in granite: Eng. and Min. Jour., vol. 70, 1900, p. 161, figs. 1, 2.

a structure it is important to make sure that the grinding of the section has not in any way modified the original fractures. Tarr adds that at Cape Ann the rift does not traverse the "knots" or the basic dikes that cross the granite.

Whittle gives two sketches made from polished surfaces of a well-known granite quarried by the Maine and New Hampshire Granite Company at Redstone, N. H. One of these sketches, made from a surface running at right angles to the rift, shows quartz and feldspar grains traversed by a generally parallel set of lines corresponding to the rift planes. The lines are more numerous in the feldspar than in the quartz grains. The other sketch, made from another specimen, shows besides the rift lines another less pronounced set intersecting these at right angles. This second set corresponds to the grain. Whittle calls attention to the fact that notwithstanding the marked rift and grain at this quarry the stone stood a compression test of 22,370 pounds to the square inch, and was, therefore, not appreciably weakened by the microscopic fractures. A visit made by the writer in 1906 to the quarry at Redstone, N. H., has corroborated Whittle's observations. The details of the rift and grain structure observed there will be discussed in a future publication.

Another peculiarity of rift is that the angle of its inclination may at some places be modified by gravity. Thus in some localities a block will split at one angle from the top, but at another from the side; or, again, at one angle where the mass of the block is at the right and at another where it is at the left of the line of fracture. Experienced granite workmen at Concord, N. H., and Quincy, Mass., report that at some places a block that would show a horizontal rift when split from one point of the compass (say the north) acquires an inclined rift if split from the south or the east or west. The cause of this is not apparent. There are also indications that a slight alteration of the feldspars may improve the rift. Finally, as is well known to granite quarrymen, rift and grain are modified by temperature, the effect of winter cold in New England (frost?) being to intensify the rift and grain where they are weak.

A Norwegian geologist, Carl C. Riiber, in a work on the granite industry of Norway [a] describes an augite syenite with inferior rift and grain, in which the cleavage planes of the individual feldspar crystals are parallel to the two cleavage planes of the rock. No such relationship between rift and mineral cleavage has yet been made out in the Maine granites.

Among the many thin sections prepared for this bulletin there is one from the medium-grained biotite-muscovite granite of C. E. Hudson's Weskeag quarry, near Pleasant Beach, South Thomaston, which

[a] Norges granit industri, Norges Geologiske undersogelse, Aarbog for 1893, No. 12, p. 45.

shows the rift; and this is also quite marked in the hand specimen. It consists of exceedingly delicate fractures that meander across the quartz particles and some of the feldspars in a roughly parallel direction. These cracks are filled with a highly refracting mineral (calcite or muscovite?), showing that the fractures are not recent. (See fig. 1.)

Herrmann[a] states that in Saxony the rift is parallel to the horiontal sheets or joints. That is true for short distances in the Maine quarries, but where the rift is horizontal and the sheets curve it crosses the sheets, and of course where the rift is vertical it crosses them throughout. Exceptionally, in one of the quarries at Quincy, Mass., a foreman reported to the writer a deflection of the rift in apparent relation to the increasing inclination of the sheets. Pl. III, *A*, shows the relations of the rift to the sheets at the Ryan-Parker quarry on Crotch Island. The structural diagrams accompanying the quarry descriptions show the relation of the rift of grain, when vertical, to the various joints.

FIG. 1.—Outlines of minerals in thin section (four-fiftieths inch square) of biotite-muscovite granite from Weskeag quarry, near Pleasant Beach, South Thomaston, showing parallel rift cracks crossing quartz and feldspar particles (marked *q* and *f*). The finely shaded parts are muscovite and biotite; the banded area is oligoclase. The black pentagonal area is a crystal of garnet.

Rift and grain data were collected at 53 quarries of granite proper. At 29 of these the rift was vertical and at 24 it was horizontal and the grain was vertical. The courses of the rift and grain are distributed as follows:

Courses of rift.

	Number of quarries.
N. 10° W.-N. 10° E	6
N. 22°-50° W	5
N. 30°-77° E	3
N. 60°-70° W	9
E.-W. to N. 85° E. and N. 80° W	6

[a] Herrmann, O., Steinbruchindustrie und Steinbruchgeologie, Berlin, 1899, p. 109.

Courses of grain.

	Number of quarries.
N	2
N. 20°–25° W	2
N. 45°–75° E	4
N. 45°–72° W	6
E.–W. to N. 80° E	10

It appears, therefore, that when rift or grain is vertical the east-west and west-northwest to northwest courses are the most common, and next the north and east-northeast to northeast courses.

Rift and grain are not always pronounced. Either or both may be very feeble or may be absent. At some of the Redbeach quarries, owing to the absence of both, it is difficult to hammer out even a good hand specimen.

At the Armbrust quarry, in Vinalhaven, there is a horizontal rift confined to a 4-foot mass striking across the hill with a N. 65° W. course.

The presence of fairly good rift or grain is an important economic factor in the granite industry, for it diminishes both the amount of labor in drilling for blasts and in splitting.

The cause of rift structure and the relative time of its formation are not yet known. If rift were always vertical it might appear to be closely related to those joints which are nearly parallel to it; but that would not explain the rift when horizontal, and horizontal rift can not be related to the sheets, which it intersects at various angles in many granites. In general it is evident that since it crystallized granite has been subjected to strains that have caused either two sets of vertical microscopic fractures extending at right angles to each other, one more pronounced than the other, or one set of similar horizontal fractures crossed by a vertical set.

That the rift is a factor in the crushing strength of granite is shown by the results of tests of Mount Waldo granite from Frankfort, blocks of which when placed on the bed—that is, with pressure applied at right angles to the rift—showed an ultimate strength to the square inch of 31,782 to 32,635 pounds (average, 32,208), but when placed on the side—that is, with pressure applied parallel to the rift—showed an ultimate strength of from 29,183 to 30,197 pounds (average, 29,690). In the first test the first crack appeared in the block at a pressure of from 120,000 to 123,300 pounds (average, 121,650) and in the second test it appeared at one of 107,400 to 112,600 pounds (average, 110,000 pounds).[a]

[a] Reilly, J. W., Ordnance Rept., tests of materials, etc. (1900), 1901, p. 1119.

SHEETS.

The division of granite into "sheets" or "beds" by jointlike fractures which are variously curved or approach horizontally, being generally parallel with the granite surface, attracted the attention of geologists long ago. Although this is the most striking feature in every granite quarry and largely makes the granite industry possible, there is a great diversity of opinion as to its cause. Whitney[a] writes:

The curves are arranged strictly with reference to the surface of the masses of rock, showing clearly that they must have been produced by the contraction of the material while cooling or solidifying, and also giving very strongly the impression that, in many places, we see something of the original shape of the surface as it was when the granitic mass assumed its present position.

Shaler, a few years later,[b] attributed the sheet structure to expansion due to solar heat.

C. H. Hitchcock[c] notices in New Hampshire granite "numerous joints, the planes of which correspond very nearly with the slope of the hill," but does not undertake to explain them.

Vogt[d] states that the sheets in granites of southeastern Norway measure from 6 inches to 6 feet in thickness and dip from 8° to 33° on the sides of the mountains, toward the valleys, but that they are horizontal on top and approximately parallel to the surface. He shows that they are of preglacial origin, attributes them to the same cause that is postulated by Whitney for those in California, and regards them as parallel to the original surface of the granite masses.

Harris,[e] referring to the English granite quarries, writes: "In every quarry we visited we found that the direction of the 'beds' approximately corresponded with the outline of the hill on which it was situated." He offers no explanation of the phenomenon, however.

J. J. Crawford[f] describes the sheet structure at granite quarries in Madera and Tulare counties, California, as consisting of "concentric layers conforming in a general way to the contour of the hills," but suggests no cause for them.

Herrmann,[g] who made a special economic study of the granites of Saxony, writes:

[a] Whitney, J. D., Geology of California, vol. 1, 1865, Geology, p. 372; also pp. 227, 417, and figs. 49-54.

[b] Shaler, N. S., Notes on the concentric structure of granitic rocks: Proc. Boston Soc. Nat. Hist., vol. 12, 1869, pp. 289-293.

[c] Geology of New Hampshire, vol. 2, 1877, pp. 511-512 and plate opposite p. 158, showing sheet structure at the "Flume."

[d] Vogt, J. H. L., Sheets of granite and syenite in their relation to the present surface: Geol. Föreningens i Stockholm, Förhandl., 1879, No. 56, vol. 4, No. 14; also Nogle, Bemaerkninger om Granit: Christiania videnskabsselsk. Förhandl., 1881, No. 9.

[e] Harris, George F., Granites and our granite industries, London, 1888.

[f] Twelfth Rept. State Mineralogist of California, 1894, pp. 384-387 and 3 plates.

[g] Herrmann, O., Technische Verwerthung der Lausitzer Granite: Zeitsch. für prakt. Geologie, Nov., 1895, Heft 2, p. 435.

Upon closer inspection it appears that the granite sheets are elongated lenses overlying one another, of which the upper one, as a rule, has its bulging part lying in the depression formed by the two underlying lenses where they come together.

Branner[a] describes the exfoliation of the granitoid gneisses in Brazil, which he attributes only in part to changes of temperature. He calls attention to the fact that the linear expansion of a mass of gneiss 300 feet long at a depth of 15 feet from the surface under a surface temperature of 103° F. would amount to only 0.072 inch; and he quotes the results of Forbes, Quetelet, and others to show that the annual change of temperature can penetrate rock only to a depth of 40 feet in temperate regions and still less in the Tropics.

Merrill[b] describes Stone Mountain, in Georgia, as a boss of granite 2 miles long by 1½ miles wide and 650 feet high, which owes its form wholly to exfoliation parallel to preexisting lines of weakness. The mass appears to be made up of imbricated sheets of granite which he regards as the result of torsional strains. The bosslike form is incidental and consequent. Intermittent expansion and contraction from changes of temperature have so affected the sheets that bound the mass at the sides that they have found relief in expansion in an upward direction. These ruptured sheets are rarely more than 10 inches thick, but are 10 or 20 feet in diameter.[c]

Herrmann[d] sums up his conclusions on the subject substantially as follows: The so-called sheets are thin near the rock surface, generally only a few centimeters thick, but become gradually thicker with increasing depth. This downward increase in the thickness of the sheets is generally more rapid where the texture of the stone is coarser. The course of the sheets is not, as Vogt claims, parallel to the original surface of the consolidating rock. It is not governed by internal strains. The attitude of the sheets corresponds to the form of the present rock surface. The sheet structure is to be looked upon as the effect of the beginning and progress of weathering from the surface inward. These weathering cracks are determined by the form of the rock surface instead of that being determined by them.

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[a] Branner, John C., Decomposition of rocks in Brazil: Bull. Geol. Soc. America, vol. 7, 1896; Exfoliation, pp. 269–277; Temperature and exfoliation, pp. 285–292.

[b] Merrill, George P., Rocks, Rock-weathering, and Soils, 1897, p. 245.

[c] For description and representations of Stone Mountain see Purington, Chester W., Geological and topographical features of the region about Atlanta, Ga.: Am. Geologist, vol. 14, 1894, pp. 105–108 and Pl. IV; also Watson, Thomas L., Bull. Georgia Geol. Survey No. 9–A, 1902, p. 113, and Pls. I–VIII. See also description of another granite dome—Stone Mountain, in North Carolina—by Watson and Laney, in Bull. North Carolina Geol. Survey No. 2, 1906; Pl. XXV.

[d] Herrmann, O., Steinbruchindustrie und Steinbruchgeologie, 1899, pp. 109–111.

Turner[a] calls attention to the sheet structure and exfoliation of Fairview dome in the Yosemite.

Gilbert[b] shows that sheet structure occurs in synclinal as well as in anticlinal attitude—in other words, is parallel to hollows as well as hills—which he considers unfavorable to the theory that it is an original structure. He suggests that sheet structure may possibly be due to expansive stress consequent upon relief from compressive stress brought about by the removal of the mass into which the granite was intruded. Subordinately he notes that in the Sierras, at least, the dome structure and the parallel joint structure do not occur in the same place and that the former has resisted general erosion more successfully than the latter.

Dr. G. F. Becker, in a recent conversation with the writer, stated that he had found the granites and gneisses at the bottom of the Colorado Canyon both vertically and horizontally jointed. If these are true granites and are still in contact with the rocks into which they were intruded and show genuine sheet structure the phenomenon would conclusively prove that such structure may occur independently of solar heat and load.

Mr. S. F. Emmons similarly stated that in the Mosquito (Park) Range, in Colorado, the pre-Cambrian granite and schist are cut by horizontal joints to a depth of 50 feet below their contact with the overlying Cambrian, the joints diminishing in number downward. The original load upon the granite here consisted of at least 10,000 feet of Paleozoic and between 5,000 and 6,000 feet of Cretaceous rocks. As the granite, however, was not intruded into Cambrian sediments it must have been exposed to atmospheric erosion before they were deposited. These horizontal joints may therefore have been related to solar temperature.

Mr. G. K. Gilbert has recently studied the granite domes of Georgia and attributes their sheet structure to compressive strains. He finds that the granite in these domes[c] is not naturally divided into plates, but that the outer parts of the granite—the parts nearest the surface—are in a condition of compressive strain, which results in slow exfoliation and which enables quarrymen, by means of carefully regulated blasts, to develop joints that run approximately parallel to the surface, so that the granite is detached in sheets. As these sheets are divided into blocks in the process of quarrying the blocks expand horizontally as they are released from the general mass. In these granitic domes parting planes also develop naturally

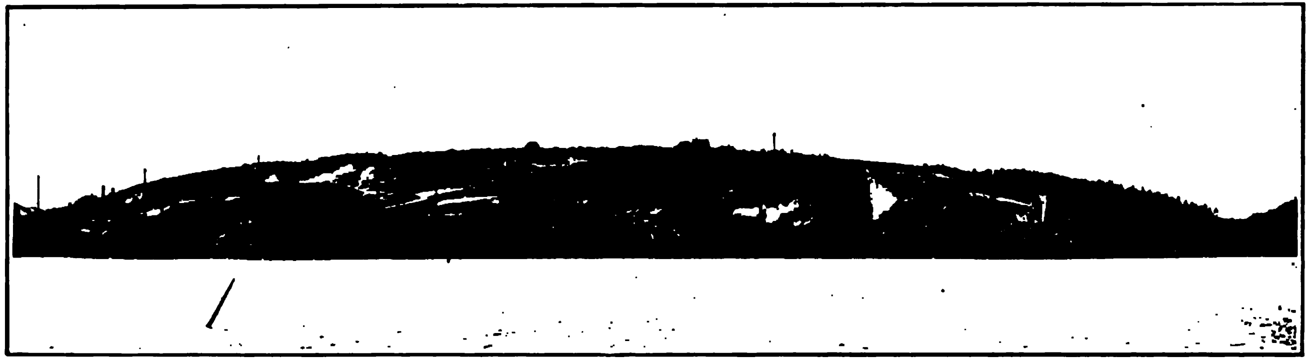
[a] Turner, H. W., The Pleistocene geology of the south-central Sierra Nevada, with especial reference to the origin of the Yosemite Valley: Proc. California Acad. Sci., 3d ser., Geology, vol. 1, No. 9, 1900; Formation of domes, pp. 312–315, and Pl. XXXVII.

[b] Domes and dome structure of the high Sierras: Bull. Geol. Soc. Am., vol. 15, pp. 29–36, and pl. 3, 1904.

[c] Letters to writer dated May 4 and June 11, 1906.

A. EAST-WEST JOINT STRUCTURE IN GRANITE ON HERON NECK AT SOUTH END OF GREEN ISLAND.

Looking south-southeast from Hurricane Island. From a photograph.



B. SOUTHERN HALF OF CROTCH ISLAND; GOSS QUARRY AT LEFT, RYAN-PARKER QUARRY AT RIGHT.

Showing concentric sheet structure crossed by vertical east-west joints. Looking west from Rock Island. From a photograph.

within a few inches of the surface, and the expansive force is there so great as to induce conspicuous buckling in the thin sheets thus formed. This buckling is illustrated in Pl. VII, *A*, from a photograph taken by Mr. Gilbert on Rock Chapel Hill, near Lithonia. The jar of blasting precipitates this sheeting action, so that several of the domes at which quarrying is in progress show long lines of freshly formed disrupted arches. Mr. Gilbert found that the horizontal elongation, or rather the elongation coincident approximately with the contour of the dome surface, amounted, by one measurement, to three-fourths inch in a length of 40 feet.

The artificial production of sheets in granite, as practiced at Bangalore, in southern India, shows similar phenomena. It is described by H. Warth[a] in substance as follows: At the surface there is a horizontal sheet of rather weathered rock 4 feet thick; below this lies a sheet of fresh rock 3 feet thick, but below this lies fresh rock without split. These sheets "are probably due to the variations of temperature, daily and seasonal." By means of wood fires plates 60 by 40 feet by 6 inches in thickness are detached in one piece. A line of fire 7 feet long is gradually elongated and moved over the granite. The effect of the fire is tested by hammering the granite in front of it, and then the fire is moved forward. The maximum length of the arc of fire is 25 feet. The burning lasts eight hours; the line of fire is advanced 6 feet per hour. The area passed over by line of fire is 460 square feet. The amount of wood used is 15 hundredweight. The average thickness of stone is 5 inches and its specific gravity is 2.62. These data show that 30 pounds of stone are quarried with 1 pound of wood. Some plates are taken out in inclined position. The action of fire is independent of the original surface of rock and also of the direction of lamination (the granite is gneissose) and of veins. The uniformity in the thickness of the sheets is attributed to the regulating influence of preexisting cracks.

Van Hise, in his treatise on metamorphism,[b] is inclined to attribute sheet structure to solar temperature.

Before these various views are discussed the sheet structure as exposed at the Maine quarries will be described.

Dome form and sheet structure are most finely exhibited at Crotch Island, near Stonington, and at Mosquito Mountain, near Frankfort. Pl. II, *B*, shows the structure in the southern half of Crotch Island, at Thurlow Head. The dome is oblate, measuring about 1,500 feet from north to south and 140 feet in height.

[a] The quarrying of granite in India: Nature, vol. 51, 1895, p. 272.
[b] Mon. U. S. Geol. Survey, vol. 47, pp. 434–439.

Pl. III, *A*, from a photograph of the Ryan-Parker quarry, at the southern edge of the dome, shows that the sheets rapidly increase in thickness downward—from 1 to 25 feet in a depth of 75 feet—and that they dip 20°-25° south. At the next quarry north, the Goss quarry (see p. 104), the excavation has exposed the center of the dome mass. Here the sheets dip both north and south, measure from 1 to 30 feet in thickness, and extend to a depth of fully 140 feet from the surface.

Mosquito Mountain, 2 miles south of Frankfort, in Waldo County, is an oval granite dome 545 feet high, with a north-south axis about 1 mile long and measuring about a half mile across.[a] It has a steep east face, the sheet structure of which is shown in Pl. III, *B*. On the top of this mountain, where the quarry is situated, the sheets dip gently north, west, and east, tapering out on the sides, and measure from 6 to 15 feet in thickness. At the Mount Waldo quarry, which lies 1¼ miles north-northwest of the top of Mosquito Mountain, the sheets dip 10° and measure from 8 inches to 8 feet in thickness, and the excavation averages about 20 feet in depth, about 300 feet from north to south, and 400 feet from east to west. The granite here is evidently under compressive strain, for the progress of quarrying resulted in a vertical fissure, running north-northwest by south-southeast for the entire width of the quarry and across the rift, which is horizontal. The formation of the fissure was accompanied by a dull explosive noise. At several other quarries in the State foremen report a partial closing of vertical drill holes by expansion or compressive strain of the rock. (See pp. 121, 142.)

At the White quarry, in Bluehill, the granite breaks with explosive sound when split in large sheets along a vertical rift that extends N. 50° W. The gradual increase in the thickness of sheets downward is well shown at the Stinchfield quarry, near Hallowell (Pl. IV, *B*). Their evenness and curvature are shown at the Sands quarry, at Vinalhaven (Pl. VI, *A*). At the Hurricane Island quarry (Pl. IV, *A*) the excavation is 105 feet deep. The upper sheets measure from 3 to 20 feet in thickness, but the lowest sheet is fully 60 feet thick. A good cross section of granite sheets is seen at the Crabtree & Havey quarry, in Sullivan, shown in Pl. V, *B*, which brings out their lenticular form and arrangement. The tapering end of one lens lies between the thickest parts of two others. This accounts for the apparent irregularity in the thickness of the sheets in some longitudinal sections, notwithstanding their progressive thickening downward. Compare Pl. V, *A*, taken at the same quarry, with Pl. V, *B*. Pl. VIII, *B*, also shows the tapering of the sheets, but here there has been some faulting since their formation, as is shown by the dislocation of the dike.

[a] See Bucksport topographic sheet, U. S. Geol. Survey.

A. RYAN-PARKER QUARRY ON CROTCH ISLAND. LOOKING SOUTHWEST.

Showing sheet structure; the thickest sheet measures 25 feet and is split along the rift.

B. EASTERN SIDE OF MOSQUITO MOUNTAIN, TOWN OF FRANKFORT. LOOKING NORTHWEST.

Showing sheet and dome structure and the erosion of the sheets.

Faulting of the sheets is likely to occur also along the steep joints. (See also p. 98.) Pl. IX, *A*, a view taken at the Waldoboro quarry, shows the relation of the sheet structure to the underside of the originally overlying mass of schist, a remnant of which bounds the quarry on two sides at the top. The sheets here are nearly horizontal, while the schist dips 45°.

The observations as to sheet structure made at over 100 granite quarries in Maine are here summarized:

1. There is a general parallelism between the sheets and the rock surface, resulting in a wavelike joint structure and surface over large areas.

2. The sheets increase in thickness more or less gradually downward. In the coarse-textured granites of Crotch and Hurricane islands the increase is abrupt. (See Pls. III, *A*, and IV, *A*.)

3. The sheets are generally lenses, though in some places their form is obscure. Their thick and thin parts alternate vertically with one another. The joints that separate these superposed lenses therefore undulate in such a way that only every other set is parallel.

4. On Crotch Island the sheet structure extends to a depth of at least 140 feet from the surface.

5. There are indications here and there that the granite is under compressive strain, which tends to form vertical fissures or to expand the sheets horizontally so as to fill up small artificial fissures. (See p. 34.)

The observations made in Europe and in this country, taken in connection with the various inferences geologists have drawn from them, indicate that sheet or "onion" structure in granite rocks is due to the following possible causes:

1. To expansion caused by solar heat after the exposure of the granite by erosion.

2. To contraction in the cooling of the granite while it was still under its load of sedimentary beds, the sheets being therefore approximately parallel to the original contact surface of the intrusive.

3. To expansive stress or tensile strain brought about by the diminution of the compressive stress in consequence of the removal of the overlying material.

4. To concentric weathering due to original texture or mineral composition. This action would be chiefly chemical and would be aided by vertical joints and by any superficial cracks due to expansion and contraction under changes of temperature.

5. To compressive strain akin to that which has operated in the folding of sedimentary beds.

6. To the cause named under 1 at the surface, but to the cause named under 5 lower down.

These propositions will be considered in the order given:

1. Solar heat may produce a certain amount of exfoliation in thin sheets at the surface, as is proved experimentally in the fire method of granite quarrying in India (p. 33), but as it penetrates only to a depth of 40 feet and as sheet structure is known to occur on Crotch Island, Maine, at a depth of 140 feet and at Quincy, Mass., at a depth of 175 feet, it is quite inadequate to account for sheets that are 20 to 30 feet thick and 100 to 175 feet below the surface.

2. In view of the load under which granite was probably formed, as shown by the well-known calculations of Sorby and Ward,[a] and the very gradual rate at which, therefore, it probably cooled, which is also indicated by the general coarseness of its texture, it is very improbable that the temperature at its contact surface and the temperature at depths 100 or 200 feet below could have so greatly differed as to bring about such a system of joints by contraction.

3. As Gilbert states, in suggesting the theory of fracture by relief of tensile strain through the erosion of overlying masses, we have no distinct knowledge of it. It is a possible explanation.

4. Careful inspection of the rock on both sides of the sheet joints fails to show any difference in texture or mineral composition. The sheet structure traverses both rift and flow structure, and it would be possible to procure specimens showing a sheet joint traversing a single crystal of feldspar. Whatever chemical action has taken place along the sheet joints is of secondary character. Acid waters may have gained access to the joint, but have not caused it. (See matter under heading Discoloration, "Sap," etc., p. 52.)

5. The condition of strain described by Merrill and Gilbert as existing in the granite domes of Georgia and by Niles and Emerson in the gneiss at Monson, Mass.,[b] and occurring to a lesser extent in some Maine quarries (see pp. 93, 112, 121, 155), shows that granite and gneiss are in places still under compressive strain. Another instance occurs at the quarry of the New England Granite Works, at Concord, N. H., recently visited by the writer. The foreman at this quarry was in the habit of calling certain sheets, marked by the absence of discoloration, "strain sheets," to distinguish them from the others. At one place a northwest-southeast compressive strain had actually extended the strain sheet about 5 feet, and also caused a vertical fracture that extended over 15 feet diagonally from the north-south working face to a point on a vertical east-west channel 5 feet back of the

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[a] Sorby, H. C., On the microscopic structure of crystals, indicating the origin of minerals and rocks: Quart. Jour. Geol. Soc. London, vol. 14, 1858, pp. 453 et seq.; Ward, J. Clifton, On the granitic, granitoid, and associated metamorphic rocks of the Lake district: Ibid., vol. 31, 1875, pp. 568-602.

[b] Niles, W. H., Some interesting phenomena observed in quarrying: Proc. Boston Soc. Nat. Hist., vol. 14, 1872, pp. 80-87, and vol. 16, 1874, pp. 41-43. Emerson, B. K., Geology of Old Hampshire County, Mass.: Mon. U. S. Geol. Survey, vol. 39, 1898, pp. 63-65.

A. HURRICANE ISLE QUARRY; EASTERN END.

Showing the lower 60-foot sheet overlain by 20-foot sheet and crossed by vertical east-west joint and by diagonal joint.

B. STINCHFIELD QUARRY NEAR HALLOWELL LOOKING WEST-NORTHWEST.

Showing the sheets gradually increasing in thickness downward, crossed by joint (C) and overlain by glacial drift.

face, closing up the channel to half its original width. The practicability of developing sheet structure by the use of explosives and compressed air, as it is developed in some of the North Carolina granite quarries, shows that the rock is under a compressive strain there.[a]

All these observations bring this theory within the domain of inductive science. If sheet structure is due to compressive strain, it is due to such a strain as would produce a series of undulating fractures extending entirely across a granite mass several miles in diameter and to a depth, as far as observed, of 175 feet from the rock surface.

6. In view of the undoubted sheeting effect of expansion under solar heat within a short distance of the surface and of the fact that some of the sheets near the surface measure but a few inches in thickness, it is quite possible that very thin surface sheets have originated in this way; but in view of what was stated under 5 it seems rather probable that compressive strain is the main factor in producing massive sheets. At the surface both causes may have cooperated. The progressive thickness of the sheets downward indicates that the operation of this strain is evidently also dependent upon distance either from the present surface or from a former surface or contact.

According to this view sheet structure may be said to exert a controlling influence upon surface forms, yet it seems quite admissible that granite domes as conspicuous as Stone Mountain, in Georgia, and Fairview Dome, in California, notwithstanding all the exfoliation that has taken place on them or the erosion they may have suffered, may still retain some degree of parallelism between their present form and the original contour of the granitic intrusions of which they are parts. This may be true, also, of the granite hills of Mount Desert.

The probability being admitted that the general parallelism between the present surface and the sheet structure is the result of erosion that followed the sheeting, the question still remains, What has determined the form and location of the domes? These may possibly be referred to major arches (anticlines) in the folds of the stratified rocks which originally overlay the granite. The crustal movement that produced these folds may also have brought about the intrusion of the material that formed the domes beneath them.

Although the sheet structure and the rock surface are very generally parallel, they are not universally so, as may be seen on the west flank of Mosquito Mountain, shown in Pl. III, *B*, which has evidently been partially eroded, and at the Clark Island (p. 126) and Sprucehead (p. 124) quarries, where the rock surface and the sheet structure were also found to be discordant.

[a] Watson, T. L., and Laney, F. B., The building and ornamental stones of North Carolina: Bull. North Carolina Geol. Survey No. 2, 1906, pp. 157–160.

Sheet structure in granite so much resembles the structure of folded stratified rocks that underground water circulates in practically the same way along the fracture planes of one and bedding planes of the other. The exudation of water along sheet joints on vertical rock faces is seen in many of the Maine quarries, and is shown in Pl. VI, *B*.

That sheet structure is not confined to intrusives is shown at quarries in Niantic, R. I., and Milford, N. H., where it passes indifferently from the granite into the overlying gneiss.

JOINTS.

Herrmann [a] divides joints into two groups—joints formed by lateral compression, whose distances from one another are related to the coarseness of the rock texture, and joints due to expansion, some of which are parted and filled with calcite, quartz, pegmatite, or volcanic rock. That many joints are due to compressive or torsional strain, and that every such strain resolves itself into two components, resulting in two sets of joints that intersect at an angle of about 90°, each forming an angle of about 45° with the direction of the strain, are facts now generally recognized. Crosby [b] has suggested that torsional strains may have been supplemented by vibratory ones in causing joints. Becker,[c] in a recent paper, shows that four or even more than four systems of joints may be due to a single force. He also shows that subsequent strain on a region thus jointed would tend to produce motion along the previously formed joints rather than a new system of jointing. It is conceivable that if a region had been jointed and afterwards subjected to a tensile strain, some of its joints might be parted, and if they were very deep the openings might become filled with volcanic matter from below, or, if not, with matter from above, infiltrated from overlying rocks. That motion has occurred along some of the joints in the Maine quarries is evident from the polished and striated surfaces of the joints as well as from the faulting of the sheets.

The structural diagrams in Part II, accompanying descriptions of the quarries, show the course and dip of the joints at the Maine quarries. The intersection of sheet structure by joint structure is shown in Pls. IV, *A*, *B*; V, *B*; VI, *A*, *B*; VIII, *A*; IX, *A*. The conspicuous east-west system of joints as seen on Crotch Island is shown in Pl. II, *B*, and as seen in the region of Vinalhaven, on Heron Neck, at the south end of Green Island, in Pl. II, *A*.

[a] Op. cit., p. 103.

[b] Crosby, W. O., The origin of parallel and intersecting joints: Am. Geologist, vol. 12, 1893, pp. 368–375.

[c] Becker, George F., Simultaneous joints: Proc. Washington Acad. Sci., vol. 7, July, 1905, pp. 267–275, Pl. XIII.

A

B

CRABTREE & HAVEY QUARRY IN SULLIVAN.

A. South side, showing irregularity in thickness of sheets owing to their lenticular form: also 9 black knots. The cuts are along grain and hard way. B. East wall, showing lenticular form of sheets in cross section on a joint face.

Joints are exceptionally as curved "as the side of a ship." Thus at the White Granite Company's quarry, near Bluehill, there is a curved joint that covers a large segment of a circle and is continuous with two vertical joints, one of which strikes N. 50° W., and the other N. 52° E. This, as well as the sheet structure intersected by it, is shown in Pl. VI, *B*.

Possibly related to such curved joints are what some New England quarrymen term "toe nails." These joints strike with the sheets, but extend only from one sheet surface to the next, and have a curve which sharply intersects that of the sheet structure. Such joints seem to be due to a strain different from that which produced the sheets.

A tabulation of 179 observations of joint courses made by compass at 80 Maine quarries of granite proper yielded the following results:

Courses of joints in granite as determined by 179 observations made at 80 quarries in Maine.

Direction.	Number of observations.
N. 12° W.–N. 15° E	19
N. 20°–30° E	13
N. 20°–30° W	8
N. 32°–50° E	25
N. 35°–50° W	18
N. 55°–70° E	19
N. 55°–70° W	27
E.–W. to N. 75° E. and N. 75° W	50

The joints of the dominant system extend approximately east to west; those of the systems next most common extend approximately northeast and northwest, east-northeast, and west-northwest, and north and south.

The spacing of the joints varies considerably, ranging from 1 foot to 500 feet, but usually from 10 to 50 feet.

In some localities the jointing is very irregular. Thus at the Ellis & Buswell (Ross) quarry, near Biddeford (fig. 39, p. 182), the granite is broken up into various polygons, which at the surface, where weathering has made inroads, resemble bowlders. Quarries opened in such places are called bowlder quarries. Another sort of irregularity in joints consists in their discontinuity or intermittence, their strike and dip for the short spaces in which they occur being uniform.

HEADINGS.

In some places joints occur within intervals so short as to break up the rock into useless blocks. For a space of 5 to 50 feet the joints may be from 6 inches to 3 feet apart. A group of close joints is called by quarrymen a "heading," possibly because, when practicable,

such a mass is left as the head or wall of the quarry. Pl. VIII, *A*, shows a typical heading on Dix Island. Pl. IX, *B*, from a photograph taken at the Longfellow quarry, near Hallowell, shows the intersection of two headings, one striking about northeast, the other about northwest; also the flexuous course of the northwest set of joints. Headings afford ample ingress for surface water, and consequently the granite within a heading is generally badly stained, if not decomposed. This will be referred to more fully under the heading " Decomposition " (p. 54).

An interesting feature of both headings and joints shown in some of the deeper quarries at Quincy, Mass., which may be found in Maine as the quarries are deepened, is their vertical discontinuity. A heading occurring at the surface may disappear below, or a heading may abruptly appear a hundred feet below the surface and continue downward.

Headings are not easily accounted for. They may be produced by vibratory strains that recur at intervals of time. If they are so caused, the character of the fractures in some headings indicate that the strains are very complex.

The courses of headings at each quarry are given in the descriptions of the quarries in Part II.

FAULTS.

The polished and grooved faces (" slickensides ") observed on many of the joints at the quarries show that faulting has occurred along them. The discontinuity of the sheets at some of the joints, causing, where the joints are slightly inclined, what quarrymen call " toeing in," may probably be attributed to faulting. This supposition assumes, of course, that the sheet structure was formed prior to the jointing. There seems to be good evidence of faulting on a considerable scale along the joints at Dodlin Hill, near Norridgewock, the details of which are described on page 150 and illustrated in fig. 33. Faulting occurs also along sheets, displacing vertical flow structure, at the same quarry (p. 25), as well as displacing vertical dikes, as at the Allen quarry, on Mount Desert, as shown in Pl. VIII, *B*, and referred to on page 100. The lateral faulting here has occurred both in northeast-southwest and in east-west directions. Another faulted dike is mentioned on page 110.

MICROSCOPIC FRACTURES.

In some of the Maine quarries the granite near the surface acquires a marked foliation, which appears to be parallel to the sheet structure, and possibly to the rift. This foliation is known by quarrymen as " shakes." It occures both at the top and at the bottom of

A. SANDS QUARRY IN VINALHAVEN. LOOKING S. 80° E.

Showing the curvature of the sheets, the intersecting joint face, and the N. 10° E. channeling along the "cut-off."

B. WHITE QUARRY IN BLUEHILL. LOOKING N. 10° W.

Showing the lenticular sheets crossed by a vertical joint curving from a N. 50° W. to N. 50° E. course. The black vertical streaks are "underground water" issuing from between the sheets.

the sheet, through a maximum thickness of 6 inches. It is coextensive with the discoloration known as "sap" and occurs at many places near vertical joints. Under the microscope this structure proves to consist of minute, nearly parallel fissures, of no great continuity, which traverse the mineral particles and which in the thin section examined are especially conspicuous in the quartz and the mica. The distance between these fissures measures from a tenth to a half a millimeter, or from one two hundred and fiftieth to one-fiftieth inch. The parallelism both to the sheets and the "sap" and its relation to the vertical joints indicates that the structure may be due to the freezing of surface water which has found its way to the sheets through the vertical joints and has entered the rift fissures.

The writer's attention was called to a similar structure in a quarry at Milford, N. H., consisting of short, parallel fractures along the rift, from one-half inch to 2 inches apart, having no apparent connection with joints or discoloration. This is probably due to strain affecting part of the granite mass.

SUBJOINTS.

Careful inspection shows that the joint structure in the Maine granites does not everywhere consist of a simple fracture, but that it is at many places complex. Minute fractures branch off from the joint at an acute or right angle and penetrate the rock a few inches, or the rock for a few inches on either side of the joint is traversed by microscopic fissures that are roughly parallel to it. All such structural features may properly be called subjoints.

A thin section of North Jay granite across a joint face shows two diverging subjoints that form an acute angle with each other and with the main joint and are filled with limonite and sericite (?). Single subjoints are, however, rarely found, five or six fine parallel fissures generally occurring together. In one of the quarries at Franklin (quarry of W. B. Blaisdell & Co., p. 94), the subjoints are parallel to the main joint, and as both main and subjoints are filled with calcite, the granite near the joint weathers out vertically in small slablike pieces from one-half inch to 2 inches thick, consisting of a central band of calcite, with one of granite on either side. Under the microscope one of these subjoints, measuring 0.74 mm. across, is seen to be filled with long slivers of quartz and feldspar and scales of biotite, forming a breccia. Another, 0.07 mm. wide, is filled with secondary quartz. At the T. M. Blaisdell quarry in East Franklin, Hancock County (p. 93), a northeast-southwest vertical joint has on one side numerous subjoints that meander off at right angles to it and traverse a cubical mass whose sides measure 10 to 15 feet. At the Shattuck Mountain quarry, in Calais (p. 164),

a joint striking N 25° E. has subjoints striking N. 40° E., N. 60° E., and N. 50° W.

Woodworth has studied analogous and related structures in various rocks and has described them as "joint fringe" and "feather fractures."[a]

CONTEMPORARY FRACTURES.

Recent natural fractures have occurred, so far as known to the writer, at only three places in Maine granite quarries. One of these fractures, already referred to in the discussion of the origin of sheet structure (p. 34; see also quarry description, p. 155), occurred at the Mount Waldo quarry, near Frankfort. Here the course of the fractures ran from north-northwest to south-southeast through the center of the quarry for a distance between 200 and 300 feet. The sheets removed from that part of the quarry aggregated about 20 feet in thickness. The fracture was vertical and parallel to the flow structure, but at right angles to both sheets and rift and at an angle of 25° to the strike of the grain. The other two fractures occurred at the Tayntor quarry, near Hallowell. Their course was east-west. One of these, which was 40 feet long and vertical, passed across a horizontal sheet 4 feet 6 inches thick, extending diagonally between two channel cuts that formed a right angle. Here the rift is horizontal, a faint vertical grain structure strikes N. 70° W., and a vertical flow structure strikes N. 35° W.. At Hooper, Havey & Company's quarry, in North Sullivan, the rock is under a compressive east-west strain, as it tends to fracture north-south across the grain and rift. At many Maine quarries the horizontal movement of the rock crushes the "cores" left between adjacent drill holes in making "channels."

ROCK VARIATIONS.

Under the term "rock variations" are grouped all those variations from typical granite that are due to injection, segregation, infiltration, inclusion, and steam cavities.

DIKES (GRANITIC).

The granitic dikes in the Maine quarries are of three kinds: Extremely fine grained granite (aplite), very coarse grained granite (pegmatite), and fine or medium grained granite.

Aplite differs from ordinary granite by the greater fineness of its texture and its scant content of mica. It is known by quarrymen as "salt horse" or "white horse." The courses of these dikes at each quarry are given in the diagrams or descriptions in Part II. In

[a] Woodworth, J. B., On the fracture system of joints, with remarks on certain great fractures: Proc. Boston Soc. Nat. Hist., vol. 27, 1896, pp. 169–173, pls. 1, 2.

A. ARCH PRODUCED BY THE BURSTING OF A THIN SHEET OF GRANITE-GNEISS, ROCK CHAPEL HILL, NEAR LITHONIA, GA.

Width of arch, 14 feet; height, 9 inches. Photograph by G. K. Gilbert, United States Geological Survey.

B. LOWER EDGE OF SCHIST INCLUSION IN GRANITE ON WORKING FACE OF FREEPORT QUARRY.

Showing contact of schist and granite; also schist fragments more or less completely detached from the inclusion. The black streak on the granite is ferruginous stain from the biotite schist.

thickness they range from a fraction of an inch to 6 feet, but usually from 2 inches to 2 feet.

The courses of 16 aplite dikes are distributed as follows:

Courses of 16 aplite dikes.

N.-N. 10° E	3
N. 25° E	1
N. 60°-77° E	2
N. 10°-30° W	4
N. 45° W	1
N. 60°-80° W	5

Dikes that strike in the northwesterly-southeasterly quadrants are most numerous.

In color these dikes vary from bluish gray to light and dark reddish. The texture of some aplites is so fine that the mineral particles can not be distinguished with the unaided eye; that of others is so coarse that the feldspar and mica may be thus detected. Under the microscope the dimensions of the particles range from 0.05 to 0.75 mm., the average being about 0.16 mm. for the finer ones and 0.50 mm. for the coarser ones. Some aplites have a porphyritic texture.

Two typical aplites will be described in detail. One, from the John L. Goss quarry, on Moose Island, near Stonington, is from a dike 15 inches wide and over 200 feet long, consists largely of quartz, potash feldspar (microcline), and a soda-lime feldspar (oligoclase) in particles ranging from 0.047 to 0.141 mm. in diameter, a few thinly disseminated particles of the same minerals measuring from 0.55 to 1.45 mm. and a few scales of black mica measuring up to 0.47 mm. Another aplite, from the Sands quarry, at Vinalhaven, consists mostly of quartz, but contains some potash feldspar (orthoclase and microcline), still less soda-lime feldspar (oligoclase), and a few scales of black mica. The particles range from 0.047 to 0.3 mm. in diameter.

The minerals of aplite dikes are so firmly attached to the granite on either side that the rock readily splits across both granite and aplite. Under the microscope the minerals of the dike appear to be welded, so to speak, to those of the granite. In construction the blocks containing such dikes should not therefore necessarily be regarded as places of weakness, but in a quarry at Franklin, Hancock County, the granite is close jointed for a space of a foot on either side of an aplite dike, the joints being parallel to the dike.

At the Bodwell Granite Company's quarry (see p. 168), 2 miles east of Jonesboro, Washington County, the reddish granite is traversed by a 6-foot dike of rather coarse, dark-reddish aplite, in which the higher power of the microscope shows that the source of the color lies in exceedingly minute dots of hematite. The aplite contains also muscovite, biotite, and accessory pyrite. This dike crosses the quarry in a N. 20° W. direction. A similar dike, having a like course, but only

4 feet wide, occurs at the eastern end of the quarry. A third dike, which ranges in width from 3 to 6 inches, has a N. 75°–80° E. course, and a fourth, of fine-grained material, from one-half to 1 inch wide, crosses the others with a course N. 60° W. and can be traced for 200 to 300 feet. This is evidently of later date than the others. Aplite dikes are supposed to have originated in the same deep-seated molten mass as the granite they traverse, but they represent a later stage of igneous activity. The fissures they fill were the result of various tensional strains or contractions, possibly consequent upon the cooling of the granite.

Most aplites contain a slightly higher percentage of silica than granite. Five analyses of aplites from the Far West made at the laboratory of the United States Geological Survey [a] show a range of silica from 71.62 to 76.03 per cent and an average of 74.08, which is near the maximum of silica for granites generally.

Pegmatite lies at the other extreme. Its mineral constituents range usually from one-half inch to 1 foot or even several feet in diameter. It is reported that the crystals in some pegmatite dikes measure from 10 to 30 feet in length by 1 to 3 feet in width. The chief minerals in pegmatite dikes are the same as in granite, but they occur in different though varying proportions. With these minerals are often associated tourmaline, garnet, beryl, etc. Chemically these dikes generally contain more silica than the granite. Dikes of pegmatite are, as a rule, more irregular in width than those of aplite. They generally range in thickness from 1 inch to 10 feet.

The courses of the pegmatite dikes in the Maine quarries and their relation to the structural features are shown in figs. 4, 6, 20, 21, 24, 28, 30, 31, and 33. Their courses are distributed as follows in 15 quarries:

Courses of pegmatite dikes.

	Number of quarries.
N	3
N. 20° E	1
N. 40° E	1
N. 60° E	1
N. 15°–20° W	3
N. 45° W	1
N. 65°–70° W	2
N. 80°–90° E	2
Horizontal	1

Pl. X, *B*, shows a pegmatite dike crossing the diorite (black granite) at Round Pond, in Lincoln County. At the Hallowell Granite Works (Longfellow) quarry (p. 119) a 2-foot dike consists of milk-white

[a] Bull. U. S. Geol. Survey No. 148, 1897, pp. 124, 150, 206, 219.

A. HIGH ISLE QUARRY, MUSCLE RIDGE PLANTATION. LOOKING EAST.

Showing sheets crossed by a N. 75° W. heading.

B. ALLEN QUARRY, WEST SIDE OF SOMES SOUND, MOUNT DESERT. LOOKING N. 15° W.

Showing thin lenticular sheets crossed by a vertical diabase dike, faulted on the fourth sheet from bottom of quarry; displacement, 16 inches along the sheet.

soda-lime and potash feldspars (oligoclase and microcline), smoky quartz, biotite, and muscovite (black and white mica), and garnet. The feldspars, quartz, and micas attain a length of several inches. At the North Jay quarry (p. 82) the pegmatite dikes measure up to 2 feet 6 inches in width and consist of a milk-white potash feldspar, smoky quartz, biotite muscovite, the constituents measuring several inches in diameter. At the Clark Island (J. C. Rodgers) quarry (p. 126) there are two intersecting pegmatite dikes with similar material of similar dimensions, together with black tourmaline and garnet. The granite at Fryeburg, near the New Hampshire line, abounds in pegmatite. At the Eagle gray granite quarry (p. 144 and fig. 31) two dikes, one 5 feet, the other 10 feet thick, alternate with granite 25 and 60 feet thick. The feldspar masses and crystals attain a length of 12 inches and the biotite and muscovite crystals and the quartz masses a length of 6 inches. Small garnets are abundant. Mingled with the pegmatite is some fine-grained aplitic material. There is also considerable pegmatite at the Waldoboro quarry, in Lincoln County. (See p. 142 and fig. 29.) At the Wild Cat or Willard Point quarry of the Bodwell Granite Company, now abandoned, there is a 12-inch pegmatite dike of feldspar, quartz, muscovite, and black tourmaline, which has a banded structure. It is crossed by another dike half as thick, with a difference in strike of 20°.

The origin of pegmatite has been much discussed both in Europe and in this country.[a] The coarseness of its constituent minerals indicates slow crystallization, and the irregularity of the dikes shows tensional rather than torsional strain. The banding of some pegmatite dikes and the isolated lenticular character of others indicate that the dikes were filled from heated solution, while many of them differ in no respect from dikes of igneous origin except by the coarseness of their texture. For these reasons it is thought that pegmatite dikes in granite have been formed in openings and fissures that were due, possibly, to contraction while the granite was still hot and that some of these openings were filled with matter in a state of both molten plasticity and solution under pressure, and others by heated solutions that gathered matter from the adjacent granite. Howsoever derived, this dike material crystallized very slowly.

Granite.—Finally, there are dikes that differ from all those just described, formed simply of fine or medium-grained granite. Thus

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[a] The principal American writings on the subject are: Williams, G. H., The general relation of the granitic rocks in the middle Atlantic Piedmont Plateau; Fifteenth Ann. Rept. U. S. Geol. Survey, 1895, pp. 675–684; Crosby, W. O., and Fuller, M. L., Origin of pegmatite: Techn. Quarterly, vol. 9, 1896, pp. 326–356; Am. Geologist, vol. 19, 1897, pp. 147–180; Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 720–728.

at the Settlement quarry, near Stonington (see p. 108), the coarse granite is traversed by a dike, from 4 to 12 inches thick, of light pinkish-gray granite, in which the feldspars attain a size of one-tenth of an inch (2.5 mm.), but under the microscope some are found that measure as little as 0.025 inch (0.12 mm.). This rock consists of a pinkish potash feldspar (microcline), a white soda-lime feldspar (oligoclase-andesine), smoky quartz, and black mica (biotite). At the Mosquito Mountain quarry (p. 153), near Frankfort, there is a 10-foot dike of medium-grained gray granite (quartz monzonite), with feldspars up to 0.3 inch. The potash feldspar (microcline) is about equal in amount to the soda-lime feldspar (oligoclase), the quartz is smoky, and the mica is black. At the Mount Waldo quarry (p. 155) there is a dike 200 feet wide of fine biotite granite, with coarse biotite granite on both sides of it. The feldspars of this dike measure up to 0.15 inch, but range ordinarily from 0.36 to 1.45 mm. The fine-grained biotite-muscovite granites quarried at the Sherwood quarry, on Crotch Island (spec. 25, *a*, described on p. 105), at East Bluehill (spec. 39, *a*, on p. 87), and at a small opening on Dodlin Hill, near Norridgewock (spec. 117, *a*, described on p. 152), all seem to belong to similar dikes that are not many feet in thickness. At an old quarry near Bluehill (p. 85) there is an 18-inch dike of fine-grained muscovite-biotite granite, in which the feldspars are much intergrown with quartz. The courses of these granite veins are N., N. 15° E., N. 20° W., N. 55° E., N. 70° W. All such dikes represent granitic intrusions.

VEINS.

Quartz veins are exceptional in the Maine quarries. At the old Bodwell Company's quarry on Cook's Mountain, near Redbeach, now abandoned, the red granite is traversed by a banded grayish quartz vein, about 18 inches thick, that has a course N. 25° W. and a vertical dip. It comprises three, or, in places, four bands, which differ mainly in texture and are separated by more or less pyrite in fine particles. In places this vein divides into three smaller veins, each of which is from 3 to 4 inches thick. The quartz contains some purple fluorite (lime fluoride), as determined by W. T. Schaller at the chemical laboratory of the United States Geological Survey, and a variable amount of a foliaceous lemon-colored mineral which Wirt Tassin, of the United States National Museum, has analyzed and determined as a new variety of sericite, resulting, possibly, from the alteration of a feldspar, and which is accompanied by another mineral, regarded by him as probably talc. Mr. Tassin's analysis and report are as follows:

A. EAST CORNER OF WALDOBORO QUARRY.

Showing contact between the granite in horizontal sheets and east-northeast dipping schist strata.

B. NORTHWEST WALL OF LONGFELLOW QUARRY NEAR HALLOWELL.

Showing intersection of two headings, one with a NW., the other with a N. 65° E. strike; also the progressive concentric ferruginous discoloration ("sap") from the sheet and joint surfaces.

Analysis of yellow foliated mineral specimen of quartz marked "D. XXVI, 105a, '05."

SiO_2 (silica)	53.28
Al_2O_3 (alumina)	23.06
Fe_2O_3 (ferric oxide)	0.10
FeO (ferrous oxide)	4.30
MgO (magnesia)	4.09
Na_2O (soda)	0.65
K_2O (potash)	8.90
H_2O (water)	6.00

The mineral is secondary mica, probably derived from feldspar (although this is merely a conjecture), and will approximate sericite in composition. It occurs in fine scales, occasionally compacted and then resembling serpentine. Luster, pearly; color, greenish yellow; hardness, 2.5; specific gravity, 2.79 at 20° C. It is associated in the vein with quartz, pyrite, purple fluorite, and another mineral which has a greasy luster and contains magnesia, but which it was impossible to separate in a state of sufficient purity for analysis. This last mineral I believe to be talc.

DIKES, BASIC.

Dikes of dark-greenish or black, hard and dense rock (diabase, rarely basalt) are of very common occurrence in the Maine quarries. The courses of some of these dikes and their relation to the joints are shown in figs. 9, 10, 14, 31, 34, 36, 38, and 39. The courses of 23 dikes are distributed as follows:

Courses of 23 basic dikes at Maine granite quarries.

N. 10°–12° E	3
N. 22°–30° E	5
N. 40°–50° E	6
N. 70° E	1
E.-W	2
N. 15°–30° W	4
N. 45° W	1
N. 75° W	1

The northeast, north-northeast, and north-northwest courses are thus the most common. The dikes are vertical, or nearly so, and range in width from 1 inch to 7 feet or more, cutting the granite sheets with mathematical definiteness. Pl. VIII, *B*, shows one of these dikes on Mount Desert, which has a course N. 15° W., and has been faulted from east to west, or west to east, along a gently inclined sheet with a displacement of 16 inches. A few feet beyond this point the same dike has been faulted along a northeast-southwest vertical joint with a displacement of 5 feet. Although it might seem that this dike was injected into the granite before the sheet structure was formed, it is quite possible that the sheet structure preceded the dike and that at a later time faulting affected both the sheets and the dike, cracking the dike along the sheets when it did not actually fault it.

Most of these dikes are so firmly welded to the granite that hand specimens that are one-half granite and one-half diabase are readily obtained. Thin sections of the glassy rims of dikes at Bryant Pond and Fryeburg show that the dike sent out microscopic branches for short distances into the granite, in places surrounding some of its quartz particles. A dike at the Dunbar Brothers' quarry, near Sullivan (p. 113), measuring from 16 to 18 inches in width, has a quarter-inch border of light-green epidote, derived from the alteration of its glassy rim. These glassy borders are due to the rapid cooling of the material at its contact with the cold granite. A vertical diabase dike in Franklin (see p. 91) has darkened the shade of the granite and filled it with low-dipping close joints for a space of 10 feet on each side. Under the microscope the quartz particles and some of the feldspars show parallel cracks 0.25 to 1.25 mm. apart. A few typical thin sections of these dikes will be described in detail.

The center of a 7-foot dike at the Mosquito Mountain quarry near Frankfort (p. 153) shows a network of minute lath-shaped crystals of lime-soda feldspar (labradorite) partly altered to a white mica, in the meshes of which is a green hornblende; also some magnetite in fine particles and pyrite, with accessory titanite, apatite, and secondary epidote.

A 4-inch dike at the W. T. Havey (Whalesback) quarry, in North Sullivan (p. 113), shows a groundmass of fine hornblende and feldspar (plagioclase), in incomplete crystals, with magnetite and thinly disseminated larger crystals of hornblende and lime-soda feldspar (labradorite), some large quartz particles, and a little pyrite. One feldspar crystal is almost completely altered to a white mica.

A 2½-foot dike at Campbell & Macomber quarry, on the west side of Somes Sound, on Mount Desert (p. 99), shows a groundmass of fine hornblende and feldspar (plagioclase) in incomplete crystals, with magnetite (?), pyrite partly altered to limonite, and lime-soda feldspar (labradorite). Some of the particles of the latter measure up to one-tenth inch in length by one-fiftieth inch in width and are largely altered to kaolin and a white mica. The hornblende in all of these dikes is regarded as a product of the alteration of augite.

The geological age of these dikes has not been precisely determined. They are considerably more recent than the granite they traverse or the dikes of aplite and pegmatite which traverse the granite. In Pl. XI, *A*, one of these diabase dikes is shown crossing both a vein of pegmatite and a mass of diorite ("black granite"), at Round Pond, in Lincoln County.[a] (See p. 139.)

The diabase dikes are the result of an earth movement that either

[a] Some of the dikes of that part of the coast have been described by F. Bascom: On some dikes in the vicinity of Johns Bay, Maine: Am. Geologist, vol. 23, 1897, pp. 275–280, Pls. IX, X, XI.

opened previously formed joints or made new ones deep enough to be injected with volcanic material. How far this may have penetrated the rocks which overlay the granite or whether it overflowed at their surface can not even be conjectured.

At the granite quarries, wherever this course is possible, the dikes and the headings are left to form the bounding walls of the excavations.

SEGREGATIONS (KNOTS).

Quarrymen know too well that granite is often disfigured by gray or black "knots" of circular or oval irregular curved outline, ranging in diameter from half an inch to 3 feet and exceptionally even 10 feet. These were studied by geologists long ago.[a] They are finer grained than the granite in which they occur, contain nearly 10 per cent less silica, much more black mica or hornblende (which accounts for their darkness), and a little more soda-lime feldspar, and their specific gravity is about 0.09 per cent higher.

Pl. V, *A*, shows 12 knots in the vertical cuts at Crabtree & Havey's quarry, in Sullivan. As the strength and durability of the stone are in no wise affected by the "knots," the blocks containing them are used for curbing, crossings, or other constructions where color and shade are not taken into consideraton.

A thin section of a very dark gray knot from this quarry shows a much greater abundance of biotite than the granite. The feldspar and the biotite particles in the knot measure up to 0.5 mm. (one-fiftieth inch), whereas in the granite the feldspar measures up to 2.25 mm. and the biotite up to 0.75 mm.

A knot from the Palmer quarry, on Vinalhaven, is of medium-gray shade, with a very fine grained groundmass inclosing porphyritic buff-pinkish feldspars and smoky quartz particles up to about one-fourth inch in diameter. The groundmass consists of quartz, potash feldspar (microcline), soda-lime feldspar, black mica, and hornblende in particles ranging in size from 0.075 to 0.5 mm. The porphyritic particles are of quartz, potash feldspar, or soda-lime feldspar, and hornblende, and measure from 0.75 mm. up.

A very dark, almost black, knot from the Sands quarry, on Vinalhaven, consists of crowded particles of hornblende and biotite, which compose one-half the knot, the rest being mostly soda-lime feldspar and quartz. Among the knots noticed is a spherical one, 2½ feet in

[a] Phillips, J. A., On concretionary patches and fragments of other rocks contained in granite: Quart. Jour. Geol. Soc. London, vol. 36, 1880, pp. 1-22, Pl. I. Merrill, G. P., On the black nodules or so-called inclusions in the Maine granite: Proc. U. S. Nat. Mus., vol. 6, 1883, pp. 137-141. Grimsley, G. P., Basic segregations: The granites of Cecil County in northeastern Maryland: Jour. Am. Soc. Nat. Hist., Apr. and July, 1894. Daly, Reginald A., Basic segregations: The geology of Ascutney Mountain, Vermont: Bull. U. S Geol. Survey No. 209, 1903, p. 164.

diameter, at the Sands quarry, and a similar one, 5 feet in diameter, at the Webster quarry, both in Vinalhaven. One at the Mount Waldo quarry measures 6 by 3 feet and consists of a medium-gray groundmass with porphyritic feldspars up to three-fourths inch and biotite scales up to one-twentieth inch. One at the Andrews & Perkins quarries, near Biddeford (p. 179), is 10 feet long. At another Biddeford quarry the knots are egg-shaped and occur in clusters. At the Tayntor quarry, in Hallowell, there is a belt 5 to 25 feet wide, with a course N. 10° E., in which knots are abundant. This crosses the flow structure, which strikes N. 35° W.

In none of the knots is there a definite boundary separating them from the granite, excepting such as is caused by the change in the proportionate abundance of the darker minerals. The cause of knots is not perfectly understood. They are collections (segregations) of the darker, heavier, iron-magnesia minerals that took place while the rock was in a plastic state.

GEODES.

Small cavities lined with crystals occur in granite. They are uncommon in the Maine quarries, but at the Bodwell Granite Company's quarry, near Jonesboro (p. 169), there are several about a foot in diameter, lined with quartz crystals and epidote. The center of some of these is filled with calcite (lime carbonate) in very obtuse rhombohedra half an inch across. The large aplite vein at the same quarry has many irregular openings lined with crystals of feldspar and muscovite. At the Machias Granite Company's quarry, near Marshfield (p. 174), there are several geodes, up to 6 inches in diameter, lined with crystals of feldspar and amethyst, with the central space filled with chlorite, epidote, and calcite.

Such cavities are attributed to bubbles of steam or gas that were in the rock while it was in a molten state, which gave room for the growth of crystals and later became filled with epidote and calcite.

INCLUSIONS.

Not to be confounded with "knots," although some of them are equally dark and occur near them, are irregular or angular particles of various schistose rocks which the granite incorporated into itself during its intrusion. They can usually be distinguished from the knots by their different microscopic structure. Inclusions of this kind occur here and there in the Maine quarries. Thus, at the Stimson quarry, in West Sullivan (p. 111), they measure about 1 inch, more or less, across, and consist of a fine-grained plicated biotite schist with a very little andesine feldspar.

But inclusions also occur on a large scale. Thus, at the Freeport quarry (p. 78), 30 feet below the surface of the granite and completely

surrounded by it, is a mass of biotite schist between 30 and 40 feet long and 3 feet thick, striking north and dipping 35° east. In quarrying, this mass has been cut from east to west. Under the microscope this is a coarse biotite quartz and feldspar (oligoclase) schist. It is probably of sedimentary origin. Pl. VII, *B*, shows part of the jagged edge of the lower portion of the inclusion and two isolated fragments of it in the granite. The granite below one of the protruding angles of the inclusion is badly stained by ferruginous water coming from the schist. In some parts of this inclusion there are streaks of pegmatite consisting of feldspar (oligoclase-andesine) and quartz. The period of its formation is uncertain.

CONTACTS.

At the Waldoboro quarry the original contact of the upper part of the granite mass with the lower part of the remnant of the schist mass, which once overlay that region and into which the granite was intruded, is exposed. (See Pl. IX, *A*, and p. 142.) This schist is a hornblende-biotite-quartz schist containing some andesine feldspar, also accessory titanite and zircon. It is a metamorphosed rock, probably of sedimentary origin. At the opposite or southwest end of the quarry (see fig. 29) the relations between the schist and granite are very complex, and a considerable mass of pegmatite intervenes in places. The granite sends small dikes into the schist and also contains inclusions of it. The granite was erupted after or during the folding of the schist, otherwise it would have become a gneiss.

MINERALS ON JOINT FACES.

Joint faces in granite are in some places coated with minerals which do not occur in the granite itself or but very sparsely. At the Sands quarry, in Vinalhaven, one of the joint faces bears very minute crystals of stilbite, a hydrous silicate of alumina, lime, and soda,[a] also hematite. In other places the face is coated with a film of crystalline calcite from one-tenth to one-fifth inch thick. Calcite occurs also similarly at one of the Redbeach quarries. (See p. 166.) A thin coating of secondary fibrous muscovite or of epidote occurs at several quarries. At the W. B. Blaisdell quarry, in Franklin, certain joints are coated with crystalline calcite to a thickness of one-fourth inch, forming in places banded veins. (See p. 41.) A thin section of the granite away from the joint does not show any carbonate, but Mr. E. C. Sullivan, of the Survey (p. 94), found 0.24 per cent of lime carbonate in a few ounces of the same specimen. Other joints in the same quarry with a different strike are coated with pyrite, and from their rusty appearance are known by the

[a] Determination by Mr. W. T. Schaller, of the United States Geological Survey.

quarrymen as "iron seams." At the Bryant Pond quarry (see p. 146) one of the joints is coated with calcite (with a little epidote and pyrite) up to half an inch in thickness, and the granite on either side contains considerable chlorite, derived probably from the alteration of its hornblende. A muscovite-biotite granite quarried at Oxford (p 146) has considerable secondary muscovite developed along planes which appear to be due to close jointing. At the McMullen quarry, on Somes Sound, Mount Desert, the light buff and white feldspar is altered for the width of a foot along the steep joints to a deep reddish color. This change does not occur along the sheets. A thin section of this red feldspar shows that the color affects both potash and soda-lime feldspars alike and is due to innumerable dots of infinitesimal size, but without definite form or color under the higher powers of the microscope. They are probably hematite.

It seems probable that the calcite and pyrite are infiltrations from calcareous and ferruginous formations that once overlay the granite, but were subsequently eroded.[a]

The presence of epidote, chlorite, muscovite, stilbite, pyrite, and hematite in or near joint faces may be attributed to a process of deep-seated mineral alteration aided by percolating waters, which took up some elements and deposited others, and were also probably under pressure. These changes may have occurred subsequent to the intrusion of the diabase dikes, because the dikes also have suffered similar alteration.

DISCOLORATION ("SAP," ETC.).

Rusty (limonite) staining along the upper and lower parts of the sheets and also along the joints and headings is common in granite quarries, although some quarries are almost entirely free from it. The concentric inward growth of "sap" from the close joints of a heading is well shown in Pl. IX, *B*. The zone of discoloration along the sheets in the Maine quarries is from one-half to 12 inches, exceptionally even 18 inches, wide on each side of the sheet parting. Its width, however, decreases gradually from the surface sheets downward. In places the sap consists of two parts—an outer dark brownish zone from three-fourths to 1½ inches wide and an inner more yellowish zone from one-fourth to one-half inch wide. Generally, however, the discoloration diminishes gradually from without inward. In some quarries there seems to be a connection between the "shake" structure (p. 150) and the discoloration, since these are coextensive.

When the stone is intended for facing or trimming buildings the

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[a] One-fourth of a mile east of Fort Ann, in Washington County, N. Y., Professor Kemp and the writer observed open vertical joints in the pre-Cambrian noncalcareous gneiss filled with calcite, evidently derived from an extraneous source.

presence of sap is a serious matter, as the stained edge of each block must be split off, which adds somewhat to the cost of production.

This discoloration has been supposed to be always due to the oxidation of the ferruginous minerals of the granite, biotite, hornblende, magnetite, and pyrite, but the Maine thin sections examined by the writer do not bear out this theory. Thus one from the Tayntor quarry, near Hallowell, shows that the stain has insinuated itself into the cleavage planes and cracks of the feldspar and muscovite and in the cracks of the quartz, forming minute deposits of limonite therein, but the biotite scales and magnetite particles are generally untouched by the stain. A section taken from the "top" of the Hopewell quarry, in Sullivan, where the fresh rock has a bluish tinge and the sap a general buff color, shows that the staining extends along the cleavages and fissures and in the spaces between the minerals, but that it does not appear in connection with the biotite scales, although it is increased by the magnetite particles. A section from the upper part of High Isle, south of Rockland, where the dark sap is an inch wide and an inner lighter part is one-fifth inch wide, shows a series of roughly parallel cracks crossing the sap vertically, with subsidiary transverse cracks. These cracks and the cleavages of the feldspar and the spaces between the minerals are stained, but the staining has no connection with the biotite, and some large particles of magnetite are scarcely touched by it. (See fig. 2.) In the outer zone the limonite is darker and probably older and thicker than in the inner one. That "sap" is not generally due to the oxidation of the minerals of the granite is also probable from the fact that no such general discoloration appears on fresh granite surfaces, even after many years of exposure to the weather.

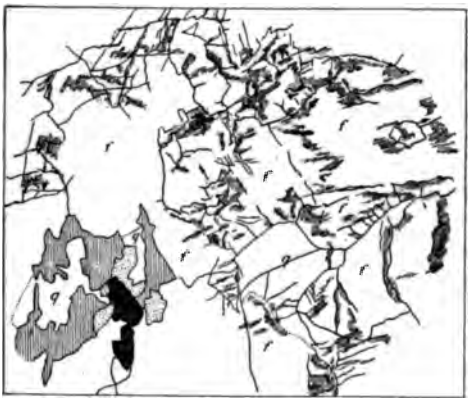

FIG. 2.—Minerals in thin section (3.76 by 4.23 millimeters = 0.15 by 0.17 inch) of biotite granite from High Isle in Knox County, showing "sap." The ramifications of "sap" (limonite stain) across and around feldspar and quartz particles (marked *f* and *q*) are independent of the biotite and magnetite particles. Fine-lined parts are biotite; fine-dotted areas are titanite; large black masses are magnetite. Some of the borders of quartz particles are shown by dotted lines.

These observations lead to the inference that the discoloration called "sap" is, in the Maine granites, not due chiefly to the oxidation of the ferruginous minerals of the granite by "underground water," but chiefly to the deposition of limonite by ferruginous surface water. The water descended along the vertical joints and then

flowed along the sheet partings and permeated the rock above and below them. This staining near the surface is intimately associated with the "shake" structure, which may be the result of frost. Whether the postglacial submergence of the Maine coast had anything to do with the discoloration is not clear.

Another kind of discoloration, which is even more serious in its consequences, appears on fresh faces of granite, either in the quarry or after its removal. This consists of sporadic rusty stains from half an inch to 1 inch in diameter, arising from the oxidation of minute particles of some undetermined ferruginous mineral. In the Maine quarries these limonitic spots are very exceptional.

Daly [a] describes a bluish-gray syenite (feldspar, quartz, hornblende, augite, biotite) that after twenty-four hours' exposure assumes a greenish tinge, which eventually becomes more or less brownish. He has demonstrated by experiment with oxygen that this change is due to the oxidation of minute blackish granules of ferrous oxide within the feldspar, giving a yellow which, in combination with the original bluish tint of the feldspar, produces a green. The large columns of the library of Columbia University, in New York, are made of this rock. Such changes, however, are uncommon in granitic rocks. The only similar one observed in the Maine granites was in the quartz diorite of Alfred, in York County. (See p. 175.)

Another kind of discoloration occurs on either side of diabase or basalt dikes, consisting mainly of various alterations of the feldspars, and their consequent change in shade or color. (See p. 91.)

Discoloration is thus of four kinds: That due to the infiltration of ferruginous water, that due to the oxidation of sporadic ferruginous minerals, that arising from the oxidation of ferrous oxide within the feldspars, and that due directly or indirectly to dikes and veins. To these should be added a possible fifth—that due to the oxidation of the generally disseminated ferruginous minerals (biotite, hornblende, magnetite) by nonferruginous water.

DECOMPOSITION.

Notwithstanding the strength and durability of granite, it is liable, under certain conditions and in the course of long time, to decompose into a clayey sand. This is the result of its physical, mineralogical, and chemical constitution and properties. One of the most striking illustrations of this is the occurrence in some of the Maine quarries of "beds" of sand or decomposed granite within the fresh granite, either between the sheets away from headings or within the headings

[a] Daly, Reginald A., The geology of Ascutney Mountain, Vermont: Bull. U. S. Geol. Survey No. 209, 1903, pp. 51–53.

and along or across the sheets. Thus at the Palmer quarry, in Vinalhaven, 20 feet below the surface in the face of the quarry there is a bed of granite sand 18 inches thick between two sheets, which at that point dip about 10° into the hill. On the southeast side of the Longfellow quarry, near Hallowell, some of the sheets within a wide heading include granite sand beds 10 inches thick. At the Shattuck Mountain quarry, near Redbeach (see p. 165) a 6-foot heading includes a vertical layer of granite sand 8 inches thick. Specimens taken from these various sand beds show that the disintegration begins with miscroscopic fractures; in some cases the enlarged rift cracks, producing the "shake" structure described on page 40, and is followed by more or less kaolinization of the feldspars. This process consists in the loss of alkali and the taking up of water, resulting in the passing of the feldspar into a white clay (kaolin).

The joint and sheet structure affords ingress to surface water; containing its usual percentage of carbonic acid, and the "rift" or "shake" structure facilitates the kaolinization of the feldspar on either side of the sheet parting by this water. As the feldspars pass into clay the rock crumbles into sand consisting of quartz, mica, and kaolin, and of feldspar in various stages of kaolinization. In some places within the range and depth of frost a large part of this work may have been done by frost alone. The sand would there be mainly the product of the "shake" structure.

In regions which have not been swept by a continental glacier any granite mass would be covered with the products of the decomposition of its own surface. In the Tropics the abundant rainfall and the organic acids from a luxuriant vegetation materially hasten the decomposition, and granitic rocks in such regions are for these reasons often covered with many feet of sand and soil.[a] Along the Maine coast the surface of granite ledges bear in protected places an inch or so of granite sand, which represents surface disintegration since the postglacial submergence.

The incipient stage of weathering may be observed in any long-exposed granite ledge in the milky whiteness of the feldspars. This change usually attacks the soda-lime feldspars first. The black mica, owing to its content of iron oxide, is also liable to early decomposition. The process of weathering, as it affects the rock as a whole, involves the following chemical changes: A loss of lime, magnesia, potash, and soda; a gain of water, and a relative gain of silica, alumina, and iron oxide—that is, relative to the reduced weight of

[a] Branner, op. cit., p. 31.

the weathered rock. The subject of weathering of granite is fully treated in the writings of Merrill, Keyes, and Watson.[a]

The changes in granite after it has entered into buildings or other constructions are less marked than those in the natural rock, because the blocks are not then traversed by anything analogous to sheet and joint structure, and also because the years of historic time are few compared to those of geologic time. Much has been written on the decay of granite in monuments and buildings.[b] Such decay is mainly attributable to microscopic fissures produced by the unequal and repeated expansion and contraction of the different minerals of the granite under changes of solar temperature. In countries where the winter temperature is very low the action of frost within such fissures powerfully assists the process of disintegration. Thus the obelisk now in New York suffered more from three years' exposure to our climate than it had during over three thousand four hundred years in Egypt, although the fissures along which frost operated were started long before it reached this country. A minor factor in decay is the chemical action of water along fissures.[c] It is supposed that these causes of decay operate more effectively in coarse granites than in fine ones. Merrill points out that a sawn or properly prepared polished surface resists weathering more effectively than a cut or hammered one, as the latter is full of minute fractures, parallel to the surface, produced by impact, which facilitate scaling.

BLACK GRANITES.

BLACK GRANITES IN GENERAL.

CLASSIFICATION.

The term "black granites," although sufficient for general commercial purposes, includes a variety of rocks of different character, origin, and appearance—gabbros, diorites, diabase, etc. They have, however, three mineralogical features in common—they contain comparatively little or no quartz, their feldspar belongs entirely or almost entirely to the series which contains both soda and lime, and

[a] Merrill, Geo. P., Disintegration of the granitic rocks of the District of Columbia: Bull. Geol. Soc. America, vol. 6, p. 321, 1895; also A treatise on rocks, rock-weathering, and soils, New York, 1897, pp. 206–214, 236, 244, 245, 257. Keyes, Charles R., The origin and relations of central Maryland granites: Fifteenth Ann. Rept. U. S. Geol. Survey, 1895, p. 725, and pls. 42–45. See also Proc. Iowa Acad. Sci., vol. 1, pt. 3, pp. 22–24, and vol. 2, pp. 27–31, Pls. II–IV, 1895. Watson, Thomas L., A preliminary report on a part of the granites and gneisses of Georgia, 1902, pp. 299, 300, 308, 329, 331, 333.

[b] Julien, Alexis A., The durability of building stones in New York City: Tenth Census, vol. 10, 1884; Granite, pp. 370–371. Merrill, Geo. P., Physical, chemical, and economic properties of building stones: Maryland Geol. Survey, vol. 2, 1898; Granite, pp. 92–94. Also Merrill's Stones for Building and Decoration, 3d ed., 1903: Weathering of granite, pp. 434, 435.

[c] See Julien, Alexis A., A study of the New York obelisk as a decayed bowlder: Annals New York Acad. Sci., vol. 8, 1893, pp. 93–166.

they contain a considerable amount of one of the pyroxenes, or hornblende or biotite, and magnetite, which accounts for the general darkness of their shade or their greenish color.

ORIGIN.

The gabbros and diorites are more or less granitic in texture, as they crystallized under conditions resembling those which attended the formation of granite. But the diabase was in part erupted through narrow fissures, forming dikes or sheets, and at many places reached the surface, always crystallizing with comparative rapidity.

Diabase, however, occurs in Vinalhaven, as stated by Dr. George Otis Smith, " in large bodies which have the form of neither dikes nor sheets, being, in fact, part of the same masses as the diorites and gabbros."

MINERALOGICAL AND CHEMICAL COMPOSITION.

Gabbro consists essentially of a lime-soda feldspar and one or both of the varieties of pyroxene known as diallage and hypersthene. The former is a foliated silicate of iron and lime with about 12 per cent of magnesia; the latter is a silicate of iron with about 24 per cent of magnesia, and each of these minerals crystallizes differently. When hypersthene alone is present the rock is called a norite; when both are present it is a hypersthene gabbro. When the mineral olivine (a greenish silicate of iron with 50 per cent of magnesia) is present also the name olivine may be prefixed to the rock name. The accessory minerals in gabbros are ilmenite (a titanate of iron), magnetite, pyrite, apatite, biotite, garnet, and, rarely, quartz and metallic iron. The secondary minerals—that is, those derived from the alteration of the primary ones—are hornblende, chlorite, epidote, zoisite, analcite, serpentine, a white mica, and calcite. The percentage of silica in gabbros varies a little on either side of 50. Iron oxides and lime average 9 per cent each; magnesia, 6 per cent.

Diorite consists essentially of feldspar (of the series containing lime and soda) and hornblende with biotite, or biotite alone. Quartz, augite, and potash feldspar may or may not be present. The accessory minerals are magnetite, pyrite, titanite, zircon, apatite, garnet, allanite. The secondary are epidote, chlorite, a white mica, and calcite. When quartz is present the rock is called a quartz diorite. When black mica or augite are the preponderating iron-magnesium silicates the rock becomes a mica diorite or an augite diorite. In diorites the silica ranges from about 49 to 63 per cent, but in quartz diorite it rises to about 69 per cent, which is the minimum in granite. The iron oxides range from 0.52 to 9.70 per cent, the magnesia from less than 1 to over 11 per cent, but usually from 2 to 7 per cent.

Diabase consists essentially of a feldspar of the series containing lime, or soda and lime, together with a pyroxene or augite (alumina, lime, magnesia, iron), which, however, is frequently altered to hornblende or other secondary minerals; also magnetite or ilmenite or both. Olivine may or may not be present, and some specimens contain a little quartz. The accessory minerals are orthoclase, biotite, pyrite, hypersthene, apatite. The secondary ones are hornblende, a white mica, chlorite, epidote, serpentine, calcite. The percentage of silica in diabase ranges from about 45 to nearly 57, of iron oxides from about 9 to 14, and of magnesia from 3 to 9.

These "black granites," as will be seen by the foregoing description, are distinguished chemically from the ordinary granites by their low percentage of silica (45 to 67 per cent), their high maxima of iron oxides (9 to 14 per cent), and of magnesia (9 to 11 per cent), and mineralogically by their dominant feldspar not being a potash feldspar, and generally also by their considerable content of the darker iron-magnesia minerals.

TEXTURE.

The general texture of the black granites corresponds in grade to that of the fine and medium granites. In the diorites the arrangement and order of crystallization of the minerals always correspond to those of the granites, described on page 20. In some of the gabbros this is also true, but in others and in diabase the arrangement greatly differs. The feldspars are in needlelike crystals, between which the pyroxene has afterwards crystallized.

PHYSICAL PROPERTIES.

Aside from their great toughness, the diorites and the granitic gabbros probably differ but little in physical properties from granites of the same grade of texture. By reason both of their peculiar texture and their mineralogical composition, the diabases and gabbros with "ophitic" texture, described on page 136, should differ considerably in physical properties from the granites. As these stones are rarely used in large buildings, owing to the difficulty of quarrying them either in blocks of sufficient size or at low enough cost, data as to their compressive strength and other useful physical properties are not available.

The specific gravity of gabbro ranges from 2.66 to about 3, that of diabase from 2.7 to 2.98, and that of diorite averages 2.95. In these rocks it thus usually exceeds that of granite.

As the black granites are used chiefly for monumental purposes, and particularly for inscriptions, their color, susceptibility to polish, and the amount of contrast between their cut or hammered and

their polished surfaces are the physical properties of chief economic importance.

Doctor Merrill[a] explains the cause of these contrasts very satisfactorily:

> The impact of the hammer breaks up the granules on the immediate surface, so that the light falling upon it is reflected, instead of absorbed, and the resultant effect upon the eye is that of whiteness. The darker color of a polished surface is due merely to the fact that, through careful grinding, all these irregularities and reflecting surfaces are removed, the light penetrating the stone is absorbed, and the effect upon the eye is that of a more or less complete absence of light, or darkness. Obviously, then, the more transparent the feldspars and the greater the abundance of dark minerals, the greater will be the contrast between hammered and polished surfaces. This is a matter worthy of consideration in cases where it is wished, as in a monument, to have a polished die, surrounded by a margin of hammered work to give contrast.

The ordinary granites, while taking a high polish, do not afford such strong contrasts between hammered and polished surfaces as do the "black granites." In some black granites this seems clearly to be due to their larger percentage of the black minerals, but in others, as some of the quartz diorites, in which the black minerals do not exceed those in some gray granites, the cause of this marked contrast must be sought in some optical property of the soda-lime feldspar and in its relative abundance.

"BLACK GRANITES" OF MAINE.

CLASSIFICATION.

The black granites at the quarries and prospects visited by the writer include:

(1) Gabbros: Gabbro, hypersthene-olivine gabbro, norite, olivine norite.

(2) An altered diabase porphyry.

(3) Diorites: Quartz diorite, mica-quartz diorite.

The appearance and the petrographic characteristics of the stone at each quarry will be stated in Part II of this bulletin, in the descriptions of the quarries and of their products, and a classification of black granites based upon economic principles will be found on page 75. These black granites vary considerably in shade and a little in color. The olivine norite of the Heal quarry, near Belfast, is almost black, but under a side light shows small, brilliant dark-green areas of hypersthene. The Vinalhaven olivine norite is quite black and fine textured. The Addison hypersthene-olivine gabbro is black, with small, irregular white areas of feldspar. The South Berwick

[a] Merrill, Geo. P., The physical, chemical, and economic properties of building stones: Maryland Geol. Survey, vol. 2, 1898, p. 64.

gabbro is a very dark olive. The Hermon Hill rock is porphyritic and dark green. A little less dark than these, and without any greenish tinge, are the mica-quartz diorites of Beaver Lake (Calais) and the gabbros from Meddybemps Lake and Mingo Bailey's quarry, in Calais, while the quartz and mica-quartz diorites of Round Pond, East Sullivan, and Calais (Gardner) are all still lighter, and would pass for dark gray. Most of these stones take a beautiful polish, and all of them show very marked contrasts between the polished and cut surfaces. That contrast naturally is still more marked in the darker ones. The polished surfaces of most of these rocks show minute particles of magnetite. Large blocks of the Meddybemps Lake gabbro deflect the magnetic needle, and it is reported that the rock contains a very small amount of gold by assay, while platinum is reported from the Hermon Hill rock.

GENERAL STRUCTURE.

Rift.—The course of the rift at the black granite quarries is given in the quarry descriptions. No other Maine black granite has such a marked rift as that of the Meddybemps Lake gabbro.

Sheets.—The sheet structure is not so well marked in the black granites as in ordinary granites, and herein lies the chief difficulty in quarrying them. Pls. X, *B*, and XI, *B*, show the character of the sheets in the Round Pond quartz diorite. Pl. X, *A*, shows it in the Addison gabbro. The sheets there range from 3 to 17 feet in thickness. In the Meddybemps Lake gabbro the sheets are well developed, being parallel to the banding and the rift, and are spaced from 1 to 6 feet.

Joints.—The courses of the joints are shown in the quarry diagrams. Jointing in the Addison gabbro is shown in Pl. X, *A*, and in the Round Pond diorite its relation to a diabase dike is shown in Pl. XI, *A*. Generally the spacing of the joints in the black granites is small, which prevents the quarrying of blocks of very large dimensions.

VARIATIONS IN THE ROCK.

Banding.—The gabbro of Meddybemps Lake is traversed, in at least its upper part, by light-gray bands that range in thickness from one-fourth inch to 2 inches. Their lighter shade is the result of a greater proportion of feldspar. These bands dip at an angle of 15°, and run parallel to both sheet and rift structure. Pl. X, *A*, shows a similar but less pronounced banding in the Addison gabbro.

This banding represents not only the flow of the eruptive, but also different segregations of the principal minerals of the rock, alternating with one another. This structure resembles that observed in

A. PLEASANT RIVER BLACK-GRANITE QUARRY, IN ADDISON. LOOKING NORTH-NORTHWEST.

Showing the sheets crossed by frequent joints striking N. 80° E., the banding of the olivine gabbro, and several dikes of whitish quartz monzonite.

B. ROUND POND BLACK-GRANITE (UPPER) QUARRY, IN LINCOLN COUNTY. LOOKING SOUTH-SOUTHEAST.

Showing the quartz-diorite sheets crossed by a 2 foot 4 inch dike of coarse pegmatite.

certain Scotch gabbros, but in them the banding was also contorted prior to crystallization.[a]

Dikes.—The Addison gabbro is traversed by whitish dikes of fine-grained quartz monzonite, from 1 to 14 inches thick. (See Pl. X, *A*.) They have a border, from one-twentieth to three-fourth inch thick, of coarser material, in which the particles measure up to one-tenth inch in diameter. The constituent minerals, in descending order of abundance, are soda-lime feldspar (oligoclase-andesine), potash feldspar (orthoclase) in slightly less amount, clear quartz, biotite, and hornblende, together with accessory magnetite, titanite, and apatite. The texture of this dike rock differs from that of any of the aplite dikes examined from the granite quarries in that the soda-lime feldspar is mostly in lath-shaped crystals (0.37 by 0.07–0.11 mm.), although occasionally also in squarish forms, and makes up an irregular network, the meshes of which are filled with quartz.

In the mica-quartz diorite of the Beaver Lake quarry, near Redbeach (p. 164), there is a dike of grayish pinkish aplite, from 4 to 8 inches wide, which appears to be more recent than a neighboring dike of olivine basalt, as its branches cross it. The particles in this aplite range from 0.11 to 0.91 mm., averaging roughly about 0.30 mm., and consist of soda-lime feldspar (oligoclase), much less potash feldspar, quartz, and biotite. The aplite is thus a biotite granite.

Dikes of pegmatite and also of aplite traverse the Round Pond (Lincoln County) quartz diorite (see Pls. X, *B*, and XI, *A*), and pegmatites penetrate the overlying sedimentary schists. Miss Bascom has described some schists and pegmatites from points in Johns Bay, about 8 miles south-southwest of Round Pond, which are probably of the same age.[b] It is uncertain whether the lenses and dikes of pegmatite in the schists were formed prior to the veins in the diorite.

The quartz diorite of Round Pond (Lincoln County) is also traversed by a diabase dike, which also crosses one of the pegmatite dikes and is therefore of later date. (See Pl. XI, *A*.) The mica-quartz diorite of Beaver Lake, near Redbeach, in Washington County, is traversed by a dike of olivine basalt, a very fine-grained black rock consisting of needlelike crystals of feldspar (andesine-labradorite) with pyroxene, olivine, and magnetite, together with accessory biotite and a white mica.

Contacts.—The only contact of black granite with other rocks well exposed at the quarries visited in the preparation of this report is at the Round Pond quarry. (Peter Svensen & Co., p. 139.) This has

[a] See Geikie, after Teall, op. cit., p. 256.

[b] Bascom, Florence. On some dikes in the vicinity of Johns Bay, Maine: Am. Geologist, vol. 23, 1899, pp. 275–280, Pls. IX, X, XI. See also in this connection: Lord, E. C., Notes on the geology and petrography of Monhegan Island, Maine: Am. Geologist, vol. 26, 1900, pp. 329–347.

been referred to by Professor Wolff.[a] At this place there is a finely plicated quartz-feldspar (andesine acid labradorite) hornblende-biotite schist, with accessory pyroxene, titanite, and apatite, striking N. 15° E., with numerous dikes of pegmatite, up to 2 feet 6 inches thick, parallel in places to the strike of the schist. On the southwest wall of the lower quarry a tongue of this schist 10 to 15 feet thick and 40 feet long lies in the diorite, as shown in Pl. XI, *B*. It reappears on the northeast wall.[b] The contact of the diabase porphyry of Hermon Hill, near Bangor, is described on page 147.

TEXT-BOOK REFERENCES ON GRANITE AND BLACK GRANITES.

As the matter contained in the foregoing pages may not fully provide answers to all questions that may arise in the minds of persons interested in tracing the phenomena in granite quarries to their causes, the names of a few reliable general works in English on the subjects considered are here given.

Diller, Joseph S. Educational series of rock specimens collected and distributed by the United States Geological Survey: Bull. U. S. Geol. Survey No. 150. 1898.

Granites, pp. 51, 170–180; gabbro, pp. 51, 52, 278–288; diorite, pp. 241–244; diabase, pp. 264–278; basalt, pp. 51, 52, 254–256.

Geikie, Archibald. Text-book of geology, fourth edition. London. 1903.

Granite, etc., pp. 89, 90, 203–209, 402–415, 715–809; gabbro, pp. 231, 232, 256; diorite, p. 223; diabase, p. 233; basalt, p. 234.

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[a] Wolff, J. E., Details regarding Maine quarries: Tenth Census, vol. 10, 1888, p. 121.
[b] As to the schist and pegmatite, see Bascom, op. cit., p. 61.

A

B

ROUND POND BLACK-GRANITE (LOWER) QUARRY.

A. Showing the quartz diorite traversed by a small dike of pegmatite, and both crossed by a 2 foot 6 inch diabase dike. Looking west-southwest. The diorite shows joints parallel to the dike. *B*. Southwest wall, showing a tongue of schist within the diorite, crossed by sheet structure; joint (B) at the right.

PART II.—ECONOMIC FEATURES.

The practical side of the granite industry will now be considered. The sections on the tests of granite and granite quarrying are of general application, but the rest of the matter has reference only to Maine granites and quarries. A list of the more important works on granite quarries and quarrying and other matters of economic character will be found at the end, together with a glossary of both scientific and quarry terms.

TESTS OF GRANITE.

The testing of granite is a subject of considerable importance, as may be seen by its literature.[a] As pointed out by Merrill, there is danger of attaching undue importance to tests of compressive strength alone, the results of which in nearly all cases far exceed the generous margin allowed by architects beyond that required by the weightiest structures. On the other hand, there is danger of losing sight of several other important qualities which ought to be carefully tested and upon which the economic value of granite in part depends. The following tests include all the kinds made at European testing institutions or recommended by American authorities, as well as some suggested by the investigation of Maine granites.

Chemical analysis.—Chemical analysis is made in order to determine the amount of iron and lime, or to detect anything abnormal in the composition.

Determination of $CaCO_3$.—Tests are made to determine the presence of lime not combined with silicates in order to ascertain the percentage of $CaCO_3$ (lime carbonate) present. This is done by powdering and treatment with warm dilute acetic acid. (See p. 94.)

Test for discoloration.—The method applied by Daly (Bull. U. S. Geol. Survey No. 209, p. 52) seems to be well adapted for this purpose. A piece of fresh rock is immersed in a stream of carbon-dioxide gas for 20 minutes and then kept in an atmosphere of that gas for 24 hours. Another piece of fresh rock is placed in an atmosphere of purified oxygen over night and then exposed for 30 minutes to a temperature of 150° C. (302° F.). Any discoloration due to the carbonization or oxidation of the minutest particles of any mineral would be sure to show itself under these tests.

Mineral composition.—This is determined by the microscopic examination of a considerable number of typical thin sections. All the mineral constituents are noted, and the average size of the mineral

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[a] See Bibliography, p. 184.

particles in the case of the fine-textured granites is estimated. Any peculiarities of texture, rift, etc., can also be noted.

Proportions of minerals.—A method has been devised by Rosiwal, of the Austrian Geological Survey,[a] by which the approximate proportions of the chief minerals (feldspar, quartz, mica, hornblende) and their average size can be determined. This consists in tracing a network of lines intersecting one another at right angles upon a polished granite surface, at intervals so far distant that no two parallel lines will traverse the same mineral particle. The total length of the lines is measured, then the diameters of all the particles of each kind of mineral are added separately and their proportion to the total length of the lines obtained. The average size of the particles of each mineral can be also calculated from the same measurements. Although this method was primarily designed for application to the coarse and medium granites, it can be extended also to the finer ones by drawing the lines upon camera-lucida drawings made from thin sections of such granites under polarized light. As the quartz is the source of the vitreousness of the rock the determination of its amount is important. The incompleteness of the collection of polished specimens of Maine granites and the short limit of time available have alone prevented the application of this method in the preparation of this report, but the method was experimentally applied to a specimen of the coarse reddish granite from Hardwood Island, near Jonesport, and the results are given on page 173.

Polish.—Besides the manifest object of this test it also facilitates exact descriptions of color and comparisons between different granites. The size of the mica plates determines the brilliancy and durability of the polish more than does their number—that is, a considerable number of very minute mica plates is not objectionable.

Hardness.—As pointed out by Hawes[b] the hardness of certain granites is not due entirely to the quartz, which is always equally hard and brittle and which the tools do not cut but crush, but to the feldspar, which is of variable hardness and, it might be added, has different cleavages, and the proportion of which in relation to quartz also varies. Rosiwal,[c] adopting a principle established by Toula, takes a piece of smooth unpolished granite of about 2 grams weight and rubs it with emery (of 0.2 mm. diameter of particle) upon a glass or metal plate for 6 or 8 minutes until the emery loses its effectiveness. The granite is then weighed again and its loss of

[a] See Rosiwal, August, Ueber geometrische Gesteinsanalysen; ein einfacher Weg zur ziffermässigen Feststellung des quantitätsverhältnisses der Mineralbestandtheile gemengter Gesteine: Verhandl. der K.-K. geol. Reichsanstalt, vol. 32, pp. 143–175.

[b] Hawes, G. W. (edited by Merrill), Granite: Building stones of the United States and statistics of the quarry industry: Tenth Census, vol. 10, 1888, pp. 16–18.

[c] Neue Untersuchungsergebnisse über die Härte von Mineralien und Gesteinen: Verhandl. K.-K. geol. Reichsanstalt, 1896, p. 488.

volume calculated. He found, assigning to emery an arbitrary value of 1,000 as representing its average hardness, that granite from 9 localities showed the following degrees of hardness: 31.7, 38.1, 41.7, 44.8, 48.4, 50.7, 52.9, 56.6, and 67.1. The extremes of these figures show that some granites have a general hardness more than twice as great as others.

J. F. Williams[a] proposed to determine the relative hardness of granites by noting the rate of penetration of a drill of a given diameter, or by measuring the distance to which such a drill will penetrate without being sharpened, or the amount of surface of rough-pointed granite which can be reduced to a bush-hammered surface per hour. Since the introduction of pneumatic drills and surfacers these methods can be easily applied.

Compressive strength.—The methods of testing the strength of building stones have grown in precision. The first requisite is that the cubes to be tested should be sawed by diamond saws and not hammered out. The next is that the direction of both rift and grain should be indicated thereon, and that three cubes should be tested, one with pressure applied parallel to the direction of the rift, one applied parallel to that of the grain, and the third at right angles to rift and grain. Where the rift and grain are pronounced the three results will differ. As in the reports of tests made with the testing machine at the Watertown Arsenal, Mass., the number of pounds pressure at which the first crack is produced should always be given, as well as that at which the cube is crushed. It is assumed that these tests are made in a dry atmosphere.

Transverse strength, shearing strength, and compressive elasticity.—It has been found useful for certain architectural purposes to test these qualities in granite.[b]

Porosity.—Buckley points out[c] that the danger from frost depends not upon the amount of absorption but upon the size of the pore space. Rocks with large pore spaces stand frost better than those with small ones, because they do not retain the water that they absorb. Tests of porosity are therefore important. Buckley used the dry and saturated weights obtained for the samples used in computing the specific gravity.

The difference in these weights was multiplied by the specific gravity of the rock. This amount was added to the dry weight, giving the sum. The difference of the dry and saturated weights multiplied by the specific gravity of the rock was then divided by the sum. This last result is the actual percentage of pore space compared with the volume of the sample tested.

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[a] Igneous rocks of Arkansas: Ann. Rept. Geol. Survey Arkansas, vol. 1, 1890, p. 41.

[b] See Buckley, Building and Ornamental Stones of Wisconsin, pp. 396–398. Also Rept. of tests of metal, etc., Watertown Arsenal (1895), 1896, pp. 319–322, 339–351, 407–411. Some of the results as to elasticity are given on page 21 of this report.

[c] Buckley, op. cit., pp. 68, 69, 372–376, 400, 413.

Freezing and thawing.—Buckley's method[a] consists in drying 1-inch and 2-inch cubes at a temperature of 110° C. and weighing them. After being saturated in distilled water they were exposed overnight to a temperature below freezing. They were then thawed out and soaked in warm distilled water. This process was continued for thirty-five days, when they were again dried at 110° C. and weighed. Finally the same stones were subjected to the tests for compressive strength and the results compared with those for stones not thus treated.

Absorption and compression.—The complete saturation of a stone and the determination of the amount of absorption are effected by a method described at length by Buckley.[b] The saturated stone should then be tested for compressive strength and the result compared with that obtained from dry stone.

Behavior under fire.—This test is best applied to saturated specimens, which are then exposed in a laboratory furnace to a temperature up to 1,500° F. and the effect noted. Some of them can be allowed to cool gradually, but others should be immersed quickly in cold water; or they may be exposed to high temperature while under compression and then cooled slowly or quickly.[c]

Specific gravity.—The specific gravity is the weight of the stone at 16° C. compared with that of the same volume of distilled water at 4° C. All air should first be removed from the piece to be tested by boiling in distilled water. The specific gravity is also required for the test of porosity.

Weight per cubic foot.—The weight of the dry stone per cubic foot is obtained by multiplying its specific gravity by the weight of a cubic foot of water, but from this there should be deducted "the weight of a quantity of stone of the same specific gravity equal in volume to the percentage of the pore space in the stone."[d] This gives the actual weight of the stone free from interstitial water.

Coefficient of expansion.—Finally, it may be desirable to obtain the coefficient of expansion of a granite intended for some particular construction. The expansion of certain granites was determined at the Watertown Arsenal by hot and cold water baths. The stones thus tested were afterwards subjected to the test for transverse strength, when it was found that they had lost 16.93 per cent of their original strength.[e]

A list of the various tests applied to building stones by German testing institutions is given by Herrmann.[f]

[a] Buckley, op. cit., p. 71.
[b] Buckley, op. cit., pp. 64–67.
[c] Buckley, op. cit., pp. 73, 411.
[d] Buckley, op. cit., p. 70.
[e] Rept. of tests of metal, etc., p. 320.
[f] Steinbruchindustrie und Steinbruchgeologie, p. 10 et seq.

ADAPTABILITY TO DIFFERENT USES.

The successful use of granite depends upon a careful consideration of its various adaptabilities. The granites proper, as will be seen by the description of the Maine granites alone (pp. 73, 74), include stones which vary greatly in texture, color, and shade. The coarse-textured ones are best adapted to massive structures, while the fine-textured ones are better adapted to lighter structures, monuments, and statues. The reason for this is that in coarse-textured granites the large feldspars crossing the various sculptural designs at all sorts of angles produce lines and reflections that interfere with the lights and shades produced by the sculptor's design, and thus mar their effect. The fine granites are well adapted to light structures and to fine sculpture, as is shown in the delicately carved panel and the statue represented in Pl. XIV, *A* and *B*. Some coarse granites, however, lend themselves well to coarse carvings, especially when these are to be placed in the higher parts of buildings, as was the lintel of Vinalhaven granite shown in Pl. XIII, *A*. Then there is the matter of color and shade. There is large room for the exercise of artistic taste in deciding which colors and shade will best harmonize or contrast with one another in a granite structure or with the colors of other stones or materials in a composite structure. There is also room for choice between different granites in ornamental work, because of the different amount of contrast between the polished, hammered, and rough surfaces of stones of different color and texture, although the polished surface is always darkest and the hammered lightest. Tarr[a] in 1895 wrote of a demand by architects for rust-colored granite (sap) for use in connection with light-colored stone in order to produce pleasing contrasts. (See further p. 72.)

The black granites are obviously best adapted for inscriptions where legibility at a distance is the prime object, and also for all ornamental work in which more marked contrasts are desired than the ordinary granite can furnish. The black granites are sometimes combined with ordinary granite of light shade in monumental work, the die being of black granite.

GRANITE QUARRYING.

The problems that confront the granite quarryman are numerous. Their solution requires not only capital, but practical experience, judgment, a little geological knowledge, and some mathematics. It is, first of all, assumed that suitably prepared specimens of the fresh rock have been procured and subjected by competent persons, provided with the necessary machines and instruments, to the tests

[a] Economic geology of the United States, p. 363.

enumerated on pages 63–66 in order that the quality of the stone may be scientifically determined.

Exploration of surface.—The next step is a careful exploration of the granite surface, if necessary, by stripping in trenches, with a view to determine the areal extent of the quality of stone tested, the character of the jointing, the presence of headings, dikes, and veins, and the frequency of knots.

Stripping.—The thickness of soil or till upon the granite surface and that of the decomposed surface rock should be estimated. In some places the removal of this covering involves large expenditures; in others the expense is so small as to be negligible.

Sheets, rift, and grain.—A sufficient amount of vertical exploration should be made, possibly by core drilling, in order to determine the thickness of the sheets, the width of the sap, the direction and amount of rift and grain.

Quarry site.—With these preliminaries a quarry site should be selected. In this selection the inclination of the sheets and the locaton of headings and dikes should be considered, as well as the amount of stripping, the location of dumps, the drainage, and the facilities for transportation. The location of a quarry on a level tract, away from streams or shore, may entail insurmountable drainage difficulties.

Transportation.—The cost of transporting the product is obviously one of the great factors in granite quarrying. The basis of the Maine granite industry is the location of its quarries at tidewater. At many quarries schooners of 175 registered tonnage—that is, carrying from 300–350 long tons—are laden within 500 feet and some within 125 feet of the point where the stone is quarried. (See Pl. XII, *A*.) Notwithstanding the greater cost of transportation by rail and the necessity, in many places, of a second handling, Maine granite has found its way far into the interior, as will be seen by reference to the description of the quarries under the heading of "Product." This is supposed to be due to the fact that the completeness of the plants and the ability of the firms in handling large contracts has more than counterbalanced the great distance of the quarry from market. But in any case the transportation of the product any considerable distance by teams to railroad or wharf is a very serious drawback. When the quarry is at a considerable elevation above the railroad or wharf, as at Mount Waldo and Mosquito Mountain, in Frankfort, elaborate systems of gravity rail transportation must be provided. At each of these quarries this has involved about 1½ miles of railroad track, besides special engines and great lengths of steel cable.

Drainage.—In small and newly opened quarries drainage is an

A. WEBSTER QUARRY, ON PLEASANT RIVER, AT END OF WINTER HARBOR, VINALHAVEN, LOOKING WEST.

Granite-laden schooner to right. Photograph by Merrithew.

B. PAVING-BLOCK QUARRY AT VINALHAVEN. A "MOTION."

Photograph by Merrithew.

insignificant matter, but as the quarry deepens it assumes importance. Where the quarry stands at some elevation the drainage is easily disposed of by ordinary piping or siphoning, but if the quarry bottom lies below the level of the surrounding tract and if the drainage exceeds the needs of the boilers, pumping must be resorted to; but even in such places there must be some available stream or shore to carry off the water. The amount of pumping requisite varies greatly.

Water supply.—When the needs of the boilers exceed the amount supplied by the drainage, neighboring springs or brooks are resorted to. On small islands that are without streams or copious springs the question of water supply in large quarries is a serious one. At one of the Crotch Island quarries water has been brought from Stonington, a mile distant, at an expense of $110 a month, and at the High Isle quarry water is obtained by pumping from accumulations in the old quarry pits on Dix Island. This required 3,900 feet of 3-inch pipe. In order to obviate such outlays bored wells are being resorted to, by means of which it is expected that the entire drainage of these islands will be made available. As explained on page 38, it is only the joint and sheet structure that makes granite a source of water. The subject of well boring in granite will be discussed in a paper to be published by the United States Geological Survey.[a] If well boring should fail to yield an adequate supply to island quarries, the condensation of sea water could still be resorted to, as in ocean navigation.

Use of explosives and wedges.—At no point in granite quarrying is more experience and judgment requisite than in the use of explosives. The selection of the place for blasting, the size and shape of the hole, the selection of the powder, and the size of the charge are all matters requiring careful consideration. The thickness of the sheet, the proximity of joints, the vitreousness of the stone, its rift and grain structure, the physical and mathematical laws governing the action of explosives, and the direction in which the quarryman desires to split the mass are all factors in each problem.

The mathematics of the subject will be found treated in a recent book by Daw,[b] and a general description of quarry methods will be found in a report by Walter B. Smith.[c]

The practice of foremen in the thirty principal granite quarries of Maine, as explained by them to the writer, was found to be as follows: Vertical blast holes almost as deep as the thickness of the sheet are

[a] Bowman, Isaiah. Well-drilling methods: Water Sup. and Irr. Paper (in preparation).

[b] Daw, A. W. and Z. W., The blasting of rocks in mines, quarries, and tunnels, etc., pt. 1, London, 1898.

[c] Methods of quarrying, cutting, and polishing granite: Mineral Industries: Eleventh Census, 1892, pp. 612–618; also Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 4 (1894–5), pp. 446–456.

drilled by pneumatic or steam drills along a proposed line of fracture under three sets of conditions. The block to be loosened must be: (A) Bounded laterally by two free ends (consisting either of two artificial channels or two joints or headings or dikes, or else of one of these and one channel) and bounded the other way by one quarried face and the desired line of fracture; or (B) bounded laterally by one channel and the proposed line of fracture and the other way by a heading or joint and a free face; or (C) not bounded laterally by any free end and the other way only by the working face. In this case after the fracture is made the two other sides of the block must be cut either by blasting or splitting. In all these cases the boundaries of the block are the upper and lower surfaces of the sheets, and the lines of frac-

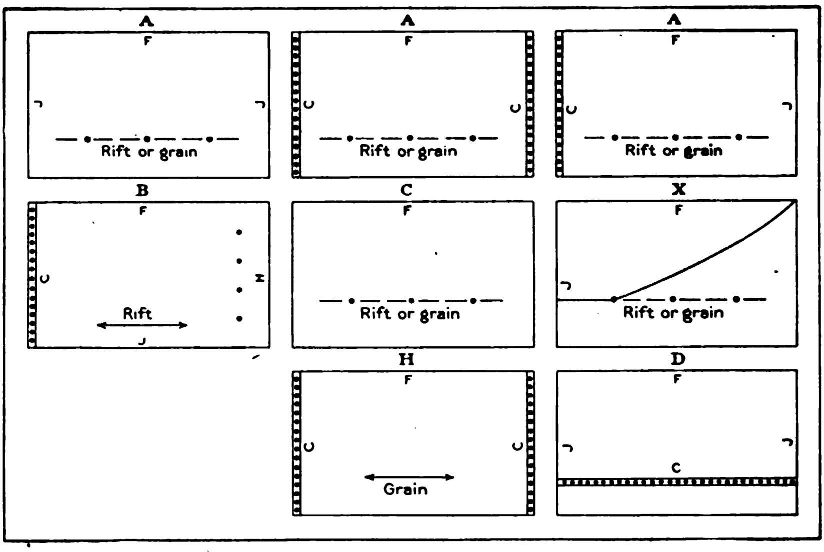

FIG. 3.—Diagrams illustrating methods of using explosives in Maine granite quarries. F, face; J, joint, heading, or dike; C, channel; H, "hard-way" or "cut-off." The round dots represent blast holes. In diagram X the diagonal crack shows effect of not channeling on right side. In method shown in diagram B explosives are not used along the rift, and in that of H (Hallowell granite) little or no explosive is used along the grain.

ture must follow either the rift or the grain. Where the grain is weak it requires double the number of blast holes to effect a fracture along it that it does along the rift. Where there is no vertical rift or grain it is impracticable to use method C, and in such cases, even with two free ends, channeling is resorted to.

Exceptionally still another method is in use, which requires only one lateral joint face and one working face (besides the sheet surfaces), the line of fracture forming the third side. But this method is regarded as hazardous by the more experienced men, for the fracture is apt to leave its direction of parallelism to the working face and swerve off diagonally to meet it. Processes A, B, and C are illus-

A. LINTEL FOR NEW YORK CUSTOM-HOUSE, CARVED FROM EVEN-GRAINED COARSE-TEXTURED BIOTITE GRANITE OF SANDS QUARRY, VINALHAVEN.

Showing adaptability for coarser sculpture. Portion at left of head unfinished. Photograph by Merrithew.

B. MONOLITHIC COLUMNS OF COARSE-TEXTURED BIOTITE GRANITE QUARRIED AT PALMER QUARRY, VINALHAVEN, FOR THE CATHEDRAL OF ST. JOHN THE DIVINE, AT NEW YORK.

Length, 51 feet 6 inches to 54 feet; diameter, 6 feet. One column in lathe.

trated in fig. 3, diagrams A, B, and C. The case without rift or grain is marked D, and the hazardous one X.

The blast holes are usually "lewis holes," which consist of two or three contiguous drill holes, with the intervening rock chiseled out, or, where less force is required, "knox holes," consisting of a circular drill hole, with two diametrically opposite lateral vertical grooves. The drill holes may be made divergent below. The "channels" are about 4 feet wide and are made either by drilling blast holes in zigzag order, which are fired singly in diagonal order, or by drilling holes on both sides of the proposed channel in close order; or else the channel consists of a single row of contiguous drill holes. This practice is found more economical than that of using a regular channeling machine. When the stone is delicate, as in the Hallowell quarries, powder is used sparingly or not at all. In the latter case channeling is done in two directions at 90°, and the operation is completed by splitting by wedges in the third. (See fig. 3, diagram H.)

At the Long Cove quarry of Booth Brothers and Hurricane Isle Granite Company (p. 128) mining is resorted to. Shafts and cross tunnels are blasted out on the plan of an inverted T (⊥) and large quantities of powder are exploded in the ends of the horizontal parts, in order to loosen a great mass of overlying rock.

After the block has been loosened by methods A, B, or C, it is broken up into minor blocks by "splitting." As is well known, splitting is now done almost entirely by the use of pneumatic plug drills. The holes are 3 to 4 inches deep, three-fourths inch in diameter, and a few inches apart. Every few feet a deeper hole is drilled. Iron wedges are then very gradually driven in between steel side pieces called "feathers."

A difference is found in blasting and splitting granite in winter and summer. A low temperature increases its cohesiveness, but, probably in connection with water, increases its fissility where the "rift" is feeble.

It is reported that in quarries in Finland the expansive power of freezing water is regularly used in splitting. This is in line with the ancient Egyptian use of the expansion of wet woody tissue. A method of blasting in use in some of the English coal mines by means of the expansion of slaked lime may be susceptible of adaption to the quarrying of the more delicate granites.[a]

In this connection should be mentioned the method recently adopted in the granite quarries of North Carolina of developing an incipient sheet structure by the use of high explosives followed by the application of compressed air. (See footnote, p. 37.)

[a] See Mosley, Paget, On a new method of mining coal: Jour. Iron and Steel Institute, London, 1882, pp. 53–62.

Utilization of waste.—In most of the Maine quarries the thin sheets and the waste material are worked up into paving blocks, which consume not only the smaller fragments, but blocks which are disfigured by sap or knots. The size of these blocks differs for different cities. The standard in New York is from 11 to 14 by 4 by 7 inches. The flat side is cut parallel to the rift. Paving stones are the only product of some quarries. The drilling at such quarries is generally done by hand. A paving-stone quarry, possibly from its often simple and temporary character, is called a "motion." (See Pl. XII, *B*.) The magnitude of the paving-stone industry in Maine can be seen from the statistics on page 183. Another use of waste is for crushed stone for macadamizing roads. The only quarry in Maine that is provided with a stone crusher for the utilization of its waste in this way is that at North Jay. The diabase dikes which are so inconvenient in some granite quarries could well be utilized in this way also, and would furnish a kind of crushed stone for which there might be a greater demand than for crushed granite. The architectural use of discolored granite (sap) is in vogue at the Cape Ann, Mass., quarries, where the Rockport public library has been made of it and the unaltered granite used for trimmings. No such thing was encountered in Maine. That sort of waste could be cheaply supplied by many quarries.

ECONOMIC CLASSIFICATION OF MAINE GRANITES.

A scientific classification of these granites has already been given on pages 24, 25. Maine granites, considered in respect to their uses, may be divided into five classes: (*a*) *Constructional*, used for bridges, docks, retaining walls, buildings, or the bases of monuments; (*b*) *statuary*, for statue and delicate monumental or ornamental work; (*c*) *inscriptional*, for inscribed dies and tablets; (*d*) *curbing*, for curbstones, straight or circular, and cross walks, and (*e*) *paving*, those which are used exclusively for paving blocks. But in order to convey an adequate idea of the great variety of these granites they have been divided into 14 groups. This classification is based upon the most conspicuous economic characteristic, be it either color or texture. The designations of these groups are: (1) *Reddish* (divided into light, bright, and dark), (2) *pinkish-buff*, (3) *light lavender*, (4) *gray* (*black and white, white dominant, the minerals affording strong contrasts*), (5) *gray, porphyritic*, (6) *buff*, (7) *greenish gray*, (8) *black and white* (*black dominant*), (9) *gray, with weak contrasts*, (10) *muscovite* (*white mica conspicuous*), (11) *fine textured*, (12) *very coarse*, (13) *paving*, fine with isolated crystals, (14) *black* (divided into black, greenish black, and medium gray). In the following table the localities where each of these

A

B

CARVINGS FROM LIGHT-GRAY FINE-TEXTURED BIOTITE-MUSCOVITE GRANITE FROM THE STINCHFIELD QUARRY, NEAR HALLOWELL, SHOWING ADAPTATION TO DELICATE SCULPTURE.

A. Part of panel at side of entrance to New York Bank of Commerce. *B*. Statue erected in 1906 at the Hall of Records in New York.

granites is quarried are given, and references are made to the pages on which a complete description of the stone can be found. Connected with those descriptions are particulars as to the quarries and the firms operating them.

Economic classification of Maine granites.

1. Reddish (medium to coarse):
   - Light—
     - Wells (p. 182).
     - Black Island (p. 96).
     - Mount Desert: Hall Quarry, Campbell & Macomber (p. 98).
     - Swans Island: Toothachers Cove (p. 115).
   - Bright—
     - Redbeach: Maine Red Granite Company (p. 165); Redbeach Granite Company (p. 167).
   - Dark—
     - Shattuck Mountain (p. 164).
     - Redbeach: Mingo Bailey & Co. (p. 165).
     - Jonesport: Head Harbor and Hardwood Islands (pp. 171, 172).
     - Marshfield: Machias Granite Company (p. 173).
     - Black Island: Redcliff quarry (p. 96).
     - Mount Desert: Southwest Harbor: Carroll quarry (p. 116).
     - Jonesboro quarries (pp. 168, 169).
2. Pinkish buff (medium to coarse):
   - Vinalhaven: Sands quarry (p. 129); Palmer quarry (p. 132); Webster quarry (p. 134); Black quarry (p. 134); Armbrust quarry (p. 135).
   - Hurricane Island quarry (p. 122).
   - High Island (p. 122).
   - Dix Island (p. 123).
   - Swans Island; Baird quarry (p. 115).
   - Biddeford: Marcille & Wormwood (p. 178).
   - Stonington: Deer Isle: Hagan & Wilcox quarry (p. 109). Crotch Island: Sherwood upper quarry (p. 106). Green Island: Latty Brothers (p. 106).
3. Light lavender (medium to coarse):
   - Stonington: Crotch Island: Ryan-Parker quarry (p. 102); Goss quarry (p. 104). Deer Isle: Settlement quarry (p. 108). Moose Island (p. 107).
   - Jonesboro: Fish quarry (p. 167).
4. Gray (medium to coarse); black and white, latter dominant, strong contrasts. Feldspar in some rocks, slightly bluish:
   - Biddeford: Ricker (p. 176); Gowen Emmons & Co. (p. 177); Andrews & Perkins (p. 179).
   - Kennebunkport: Ross quarry (p. 181); Day quarry (p. 181).
   - Bluehill: White quarry (p. 84); Chase quarry (p. 86); Howard quarry (p. 88).
   - South Thomaston: Weskeag quarry (p. 127).
   - Guilford (p. 148).
   - Norridgewock: Dodlin quarry, light (p. 149).
   - South Brooksville: Bucks Harbor quarry (p. 88); Maine Lake Ice Company quarry (p. 89).

5. Gray, with isolated lighter crystals:
   - Frankfort: Mosquito Mountain (p. 152); Mount Waldo (p. 154).
   - Searsport: Mount Ephraim (Bog Hill) (p. 157).
   - Bluehill: Collins Granite Company (p. 87).
   - Dedham: Brown (p. 90).
6. Buff (medium to coarse):
   - Millbridge (p. 174).
   - Mount Desert: Hall Quarry, McMullen & Co. (p. 97).
   - Brooksville: Wilson quarry (p. 88).
   - Sedgwick (p. 101).
7. Greenish gray (medium texture):
   - Mount Desert: Seal Cove (Herrick) quarry (p. 116).
   - Alfred: Bennett Brothers (p. 175).
8. Black and white (medium texture, black dominant):
   - Sprucehead: Bodwell quarry (p. 124).
   - Hartland (p. 149).
   - Woodstock: Bryant Pond (p. 146).
   - Norridgewock: Dodlin quarry, dark (p. 149).
9. Gray, weak contrasts (medium to coarse texture):
   - Sullivan: Crabtree & Havey (p. 110); Taylor quarry (p. 113); Hopewell quarry (p. 111); Stimson quarry and other quarries (p. 111).
   - Franklin: W. B. Blaisdell (p. 94); T. M. Blaisdell (p. 93); Robertson & Havey, and other quarries (p. 90).
10. Muscovite, white mica conspicuous (medium texture):
    - Fryeburg (p. 144).
    - Oxford (p. 146).
    - Bradbury (Hollis Center) (p. 180).
11. Fine textured (light to medium gray):
    - Jay (p. 80).
    - Pownal (p. 79).
    - Swanville: Oak Hill (p. 158).
    - Lincoln (p. 156).
    - Hallowell (p. 117).
    - Freeport (p. 77).
    - Frankfort: Mount Waldo (p. 154).
    - Bluehill. Chase (p. 87).
    - Clark Island (p. 125).
    - Long Cove (p. 128).
    - Brunswick (p. 76).
    - Crotch Island: Sherwood lower quarry (p. 105).
    - Waldoboro (p. 140).
    - Norridgewock: Emmons Taylor quarry (p. 152).
12. Very coarse (gray or pinkish buff):
    - Stonington: Spruce Island (p. 107).
    - Dedham: Brown (p. 90).
    - Franklin: Bradbury quarry (p. 95).
13. Paving (fine, with isolated crystals):
    - Vinalhaven: Pequoit quarry (p. 135); Duschane Hill quarry (p. 135).
    - Mount Desert: Hall Quarry, Allen (Snowflake) quarry (p. 99).

14. Black (fine to coarse):
  Black and black speckled—
    Vinalhaven: Bodwell (p. 136).
    Addison: Pleasant River (p. 159); Thornberg (p. 160).
    Calais: Mingo Bailey & Co. (p. 163).
  Greenish black—
    Belfast: Heal quarry (p. 157).
    South Berwick: Spence & Coombs (p. 176).
    Hermon: Hermon Hill (p. 147).
  Dark gray—
    Sullivan: Pettee (p. 114).
    Baileyville: Meddybemps Lake, Hall's quarry (p. 161).
    Redbeach: Beaver Lake quarry (p. 163).
    Calais: Gardner (p. 162).
    St. George: McConchie quarry (p. 126).
    Round Pond quarry (dark) (p. 139).
  Medium gray—
    Round Pond quarry (light) (p. 139).
    Whitefield: Jewett quarry (p. 143).

DISTRIBUTION OF GRANITE QUARRIES IN MAINE.

The map (Pl. I) shows the location of the principal quarries and groups of quarries and prospects, which include 133 separate openings, and also the relation of these to the rock areas which are described in the introductory chapter. Of these openings 92 are quarries operated in 1905. A number of unimportant paving block and underpinning quarries have been overlooked or intentionally omitted.

Quarries of granite proper.—With the exception of the important quarries at Hallowell in Kennebec, North Jay in Franklin, and the minor ones at Fryeburg and Bryant Pond in Oxford County, Pownal in Cumberland County, Norridgewock in Somerset County, Oak Hill and Lincolnville in Waldo County, and Dedham in Hancock County, all the granite quarries of Maine are along the seaboard, either on islands or on bays or navigable rivers, or within 4 miles of them. The inland quarries are all on railroads or within a short distance of them. The distance to rail from a few quarries is 3 miles, from one 5 miles, but as the product of these quarries is used entirely for monumental work the cartage is a matter of less moment. The Maine granite industry may be said to have its center in Penobscot and Blue Hill bays and the islands about them. A line drawn from Clark Island, south of Rockland, north-northeast to Frankfort, and thence about east to Franklin, in Hancock County, thence south through Bar Harbor, and thence around the islands in a southwesterly course back to Clark Island, would embrace an area of about 1,200 square miles, which would include the bulk of the granite industry.

Quarries of black granite.—There are 12 quarries of black granite, although a few obscure ones may have been overlooked. Their location is shown by a separate symbol on the map. They are in York, Lincoln, Waldo, Penobscot, and Washington counties. Of these only the Addison (in Washington County), Vinalhaven (in Knox), and Round Pond quarries (in Lincoln) are at tidewater, but as these granites are used only in small quantities for expensive work the cost of transportation is a minor consideration.

DESCRIPTION OF THE QUARRIES AND THEIR PRODUCT.

The quarries will be here described in detail by counties. The particulars in regard to each quarry come under the following heads, which will be taken up in the order given:

1. Name and location of quarry; name and office address of operator.
2. The granite—its name, color, texture, minerals, chemical composition, and physical qualities as shown by any tests. The number of the specimen collected in the preparation of this report precedes the description in each case. The words "coarse," "medium," and "fine" as applied to texture are to be understood as defined on page 20.
3. The quarry: Date of its opening, size, drainage, stripping.
4. Rock structure and rock variations under the one head "Rock structure," comprising general features, sheets, joints, headings, rift and grain, dikes, veins, knots, sap, etc.
5. The plant, with enumeration of all machines and pneumatic tools.
6. Transportation, including distance from dock or railroad, and method of transport.
7. Product, its uses and market, and the names of specimen buildings or monuments and contracts undertaken in 1905.

The counties will be taken up in alphabetic order: Cumberland, Franklin, Hancock, Kennebec, Knox, Lincoln, Oxford, Penobscot, Piscataquis, Somerset, Waldo, Washington, and York, and the towns in each county will be taken up in like order.

CUMBERLAND COUNTY.

The Granite quarries in Cumberland County are in the towns of Brunswick, Freeport, Pownal, and Westbrook.

The Grant quarry is in the town of Brunswick, 3 miles west of Brunswick village, on the south side of the Maine Central Railroad, on the Merriman farm. This quarry was not in operation in 1905.

The granite (specimen 110, *a*) is a biotite granite of medium-gray shade and fine, even-grained texture, in which the particles of quartz

measure up to about 0.4 inch, those of feldspar and mica up to 0.15 inch. Its minerals, in descending order of abundance, are potash feldspar (both microcline and orthoclase), quartz, a feldspar with both lime and soda (oligoclase-albite), and biotite, with rarely a scale of muscovite. The orthoclase has inclusions of quartz, circular in cross section, and the second feldspar is greatly altered. The rock contains accessory zircon.

The quarry opening measures about 75 by 50 by 5 feet in depth.

Rock structure: The sheets range from 2 to 12 inches in thickness and dip not higher than 5°. The joints are shown in figure 4. A marked flow structure is indicated by alternating light and dark bands, due to varying amounts of black mica and also by the parallelism of the longer axes of the larger feldspar crystals and biotite plates. The granite is traversed by a pegmatite dike, 2 to 3 inches

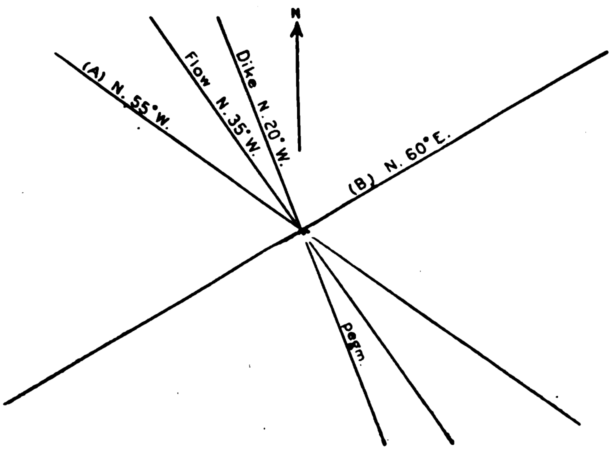

FIG. 4.—Structure at Grant quarry, Brunswick.

thick, with a course N. 20° W. The upper sheet shows considerable discoloration.

Plant, none. Transportation by team to railroad near by.

Product: The chapel of Bowdoin College, at Brunswick, was built of the same granite, but the stone was taken from another opening, near this one, which is referred to by George P. Merrill as also furnishing the stone for the First Parish Church, in Portland.[a]

The Freeport quarry is one-half mile southeast of Freeport station, on the Maine Central, on the eastern side of a hillock 80 feet high, with northeast-southwest axis. The Freeport Granite Company is now in the hands of a receiver, Wilford G. Chapman, 396 Congress street, Portland, Me.

The granite (specimen 127, *a*) is a biotite-muscovite granite of a

[a] Proc. U. S. Nat. Mus., Vol. 6, 1883, p. 171.

medium-gray shade with a slight bluish tinge and very fine, even-grained texture, with particles ranging from 0.36 to 1.28 and, exceptionally, from 0.18 to 2.5 mm. in diameter. Its minerals, in descending order of abundance, are potash feldspar (microcline, orthoclase), smoky quartz, soda-lime feldspar (oligoclase), black mica, and white mica. The soda-lime feldspar is considerably altered to kaolin and a white mica and both feldspars often have intergrowths of quartz circular in cross section. The rock contains accessory apatite. It takes a fine polish. The specific gravity was reported by F. L. Bartlett, of the Maine State assay office, as 2.627.[a] It is free from pyrite.

The quarry, first opened in 1886, now measures about 600 feet from northeast to southwest by 100 feet across, and has a working face 55 feet high. It is not below the general surface at the road

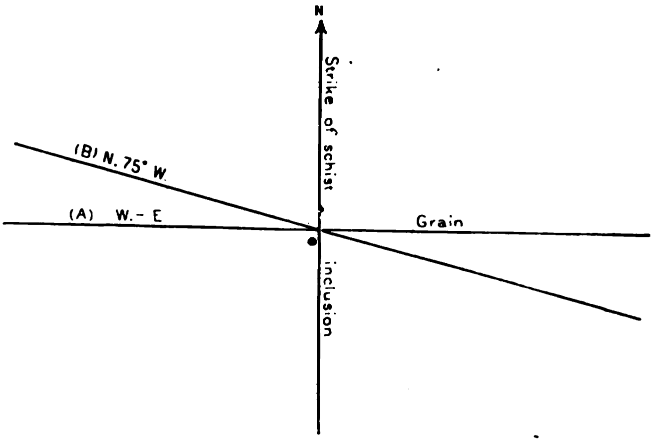

Fig. 5.—Structure at Freeport quarry, Brunswick.

that passes in front of it. The drainage offers no difficulites. The stripping consists of 2 to 5 feet of loam and sand.

Rock structure: The granite at the northeast end of the quarry is capped by about 5 feet of schist, and in its center the excavation, in proceeding in a direction parallel to the axis of the hill, has bisected an inclusion of this same schist 3 feet thick and about 40 feet long, dipping 35° E. to a point 30 feet below the surface of the granite. This schist inclusion is described on page 51. (See also Pl. VII, *B*.) About 150 feet southeast of it is another inclusion of similar material. The presence of these inclusions necessarily involves some dead work and waste. The sheets are from 1 to 8 feet thick, increasing in thickness downward, and dipping up to 10° SE. and 10° NW. Joint courses are given in fig. 5. A forms the northeast wall of quarry and recurs every 20 to 50 feet; B, at southwest end of

[a] See Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, continued, 1898-9, p. 389.

quarry, recurs at distances of 3 to 30 feet. The rift is horizontal and the grain is vertical, extending east-west. There are a few knots, up to 12 inches across, of muscovite, quartz, and feldspar. There is no sap.

The plant consists of 3 derricks, 1 hoisting engine, and 3 polishers.

Transportation is by cartage, one-half mile to railroad or three-fourths mile to dock. In 1905 the quarry was idle.

The fine texture of the stone makes it particularly well adapted for monuments. It has found its way chiefly into Massachusetts and the West. Among the monuments made of it are the Humboldt monument in Chicago and the Scott monument in Pittsburg, Pa. The front of the Maine building at the Chicago World's Fair, afterwards removed to Poland Springs, Maine, and the polished tanks at Poland Springs also came from this quarry.

The Pownal Granite Company's quarry is in the southern corner of the town of Pownal, 2½ miles north-northeast of Yarmouth junction on the Maine Central and Grand Trunk railroads. Operator, Pownal Granite Company, No. 1 Madison avenue, New York.

The granite (specimen 123, *a*) is a biotite granite of light-gray shade and very fine, even-grained texture, most of the particles ranging from 0.25 to 0.75 mm. in diameter. It consists, in descending order of abundance, of very slightly smoky quartz, potash feldspar (microcline), soda-lime feldspar (oligoclase), and black mica with accessory zircon, apatite, and magnetite. The oligoclase is much altered to a white mica and the microcline has intergrowths of quartz, circular in cross section. The polish is inferior to that of the Freeport stone.

The quarry, opened in 1880, measures 300 by 200 feet, and averages 3 feet in depth. There are from 2 to 3 feet of clay and soil stripping.

Rock structure: Flow structure at one point results in a lamination dipping 10° east, with thin black streaks of matted biotite scales. The sheets measure from 4 inches to 4 feet 8 inches in thickness and dip 10°–15° SE. in broad undulations. They have been tested with core drills to a depth of 60 feet and the lowest sheets found to be 6 feet thick. Vertical joints, striking N. 50° E., recur every 30 or 35 feet. The rift is horizontal and the grain is vertical, extending east-west. A 12-inch basic dike crosses the northwest half of the quarry with a course N. 50° E. A 1-inch pegmatite dike, with ferruginous staining, strikes N. 80° E. and dips 20° SE. Another, 4 inches thick, occurs at the west end of the quarry, dipping 10° W. There are neither knots nor rust stains nor sap.

The plant consists of 4 derricks, 2 engines, 2 steam drills, 1 steam pump, 1 compressor with a capacity of 80 cubic feet of air per minute, 4 pneumatic hand tools, 1 surfacer. The cutting plant is in New York.

Transportation is effected by cartage of 2½ miles to dock or railroad.

Product: Monuments and superior class of buildings. Market: New York. Specimen monuments and buildings: Baker mausoleum at Woodlawn Cemetery, New York; hotel at corner of Seventieth street and Central Park, and Van Norten Trust Building, corner of Sixtieth street and Fifth avenue, New York. Contracts in 1905: The French monument, Calvary Cemetery, and a building at corner of Eighty-first street and Ninth avenue, New York.

Pride's quarry is in the town of Westbrook, 3½ miles northeast of Westbrook (Saccarappa) and one-fourth of a mile north of Prides Corners. Operator, James H. Pride; address, R. F. D., Woodford, Me.

The granite (specimen 140, *a*) is a biotite granite of medium-gray color with conspicuous black mica and fine even-grained texture (particles measuring up to one-tenth of an inch across) consisting, in descending order of abundance, of potash feldspar (microcline and orthoclase), smoky quartz, a little soda-lime feldspar (oligoclase), and biotite with accessory apatite. The biotite scales are generally parallel. This stone does not fit into any of the groups described on pages 73, 74.

The quarry, opened in 1898, is 200 by 100 feet, and averages about 6 feet in depth.

Rock structure, etc.: There is a marked flow structure, dipping in places 30° eastward, which gives the granite the appearance of a gneiss. The sheets are from 6 inches to 2 feet 6 inches thick, and dip up to 5°. A heading on the east side strikes N. 10° E., and dips 55° W. The rift is horizontal and grain vertical, trending east to west. A 12-inch thick basic dike, striking N. 50° E., forms the west side of quarry. Sap from 1 to 3 inches wide in upper sheets, but none 5 feet down.

The plant consists of 3 derricks, 1 engine, and 1 polisher.

Transportation: The nearest railroad is at Westbrook, 3½ miles away. Product: Curbing and bases of monuments. Market: Local; Westbrook and Portland.

FRANKLIN COUNTY.

The granite quarries in Franklin County are in the town of Jay.

The Maine and New Hampshire Granite Corporation quarries are at North Jay. The company's office is in the Baxter Building, Congress street, Portland, Me.

The granite (specimen 118, *a*) is a biotite-muscovite granite of very light gray shade ("white granite"), and fine, even-grained texture, in which the particles range from 0.36 to 3 mm. in diameter, and consist of the following minerals, arranged in descending order

of abundance: Potash feldspar (microcline and orthoclase), clear quartz, soda-lime feldspar (oligoclase), black mica (biotite), and white mica (muscovite), together with accessory garnet, magnetite, and apatite. The general whiteness of this rock is due to the quartz not being smoky as in most granites, and also to the whiteness of the feldspars, which is thus visible through the quartz. The feldspars are mostly unaltered. The following chemical analysis of this granite, made by E. T. Rogers, was reported by Prof. John E. Wolff, of Cambridge, Mass., in 1892:[a]

Analysis of granite from quarry at North Jay.

SiO_2 (silica)	71.54
TiO_2 (titanium dioxide and Fe_2O_3 (?))	0.84
Al_2O_3 (alumina)	14.24
Fe_2O_3 (ferric oxide)	0.74
FeO (ferrous oxide)	1.18
CaO (lime)	0.98
MgO (magnesia)	0.34
Na_2O (soda)	3.39
K_2O (potash)	4.73
H_2O (water, at red heat)	0.61
S (sulphur)	Trace.
CO_2 (carbon dioxide)	Trace.
	98.59

The same analyst finds the specific gravity 2.639. A test of the compressive strength of this granite, made for the company at the Watertown Arsenal in 1892, shows that the cube cracked at 15,720 pounds per square inch and was destroyed at 16,310 pounds per square inch. An earlier test of the same granite with somewhat different results was made at that arsenal on May 6, 1882.[b] It does not take a very good polish, owing to the abundance of mica and the large size of its plates. The North Jay granite was also described by M. E. Wadsworth in 1878.[c]

The quarry, opened in 1872, consists of three openings, known by the name of "Upper," "Lower," and "Bowlder." The upper quarry measures about 425 feet from north to south by 200 feet from east to west and has an average depth of 20 feet. The lower one, adjacent to it on the west, measures 500 feet from north to south and 350 feet from east to west, with an average depth of about 35 feet. These openings are on the west side of a north-south ridge. The bowlder quarry, a little north of the other two, is about 150 feet square and 20 feet deep. The upper and lower quarries are separated by a mass

[a] See Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6, continued, 1898, pp. 218, 219.
[b] Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 5, continued, p. 961.
[c] Proc. Boston Soc. Nat. Hist., vol. 19, pp. 237–238.

10 feet thick, consisting of two large aplite dikes that have a north-south course. The drainage is natural. There are from 6 inches to 3 feet of loam on the granite surface, but in places it is bare.

Rock structure: In the center of the lower quarry there is a lamination in folds 20 feet broad and 3 feet high, occasioned by the parallelism and abundance of biotite plates along certain planes. Some of these planes show evidence of friction along them. There is also a north-south vertical structure associated with the dikes of aplite between the two quarries. The sheets range from 4 inches to 6 feet in

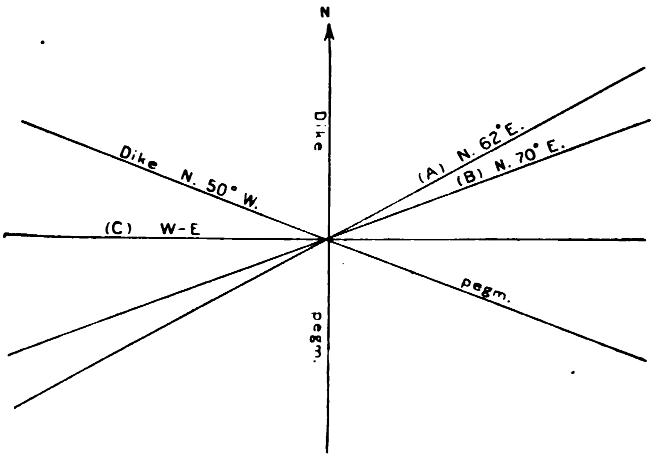

FIG. 6.—Structure at Maine and New Hampshire Granite Company's quarry at North Jay.

thickness. In the upper 25 feet the sheets are thin, but below that they become gradually thicker. In cross section they feather out alternately, or "toe in," as described on page 35. At the top of the hill and at the east side of the upper quarry they are horizontal, but on the west side they curve over westward, dipping 5°–10°, and possibly a little more in the lower quarry, governing the slope of the hill. At the north side of the lower quarry is a heading striking N. 50°–60° E., dipping 60° and also 90°. The courses of the various joint systems and dikes are shown in fig. 6. Of joints B there are four discontinuous ones in a space of 50 feet in the upper quarry. The rift is horizontal and there is no grain. The pegmatite dikes consist of milk-white potash (microcline) and soda-lime (oligoclase) feldspar, smoky quartz, biotite, and muscovite, and measure up to 2 feet 6 inches. Knots are exceptional and measure up to 12 inches across. Heading A is covered with limonite from oxidation of pyrite. Ferruginous discoloration (sap) is noticeably absent from the sheets.

The plant consists of 8 power and 2 hand derricks, 8 engines, 2 locomotive cranes, 1 compressor (capacity, 762 cubic feet per minute), 4 steam or air drills, 8 pneumatic plug drills, 2 surfacers, 14

pneumatic hand tools, 3 steam pumps, and 2 steam crushers—1 of 200 tons capacity a day, the other of 75 tons.

Transportation is had by gravity track to the Maine Central Railroad, 1,300 feet distant and 300 feet down. . This company has devised an ingenious mode of adapting an ordinary platform freight car to the transportation of thin granite blocks 12 feet square.

The product is used for monuments and buildings, and the chief market is the West. Specimen monuments and buildings: General Grant's tomb, Riverside drive, New York; Richard Smith soldiers' and sailors' memorial gateway at Fairmount Park, Philadelphia; entrance to Union Mutual Life Insurance Company's building at Portland, Me.; the Hahnemann monument, in Washington, D. C.; the Chicago and Northwestern Railway building, in Chicago; the Western German Bank, Cincinnati, Ohio, and the Union County court-house, at Elizabeth, N. J.

Rough stone, paving blocks, and crushed stone are important by-products.

Contracts in 1905: The Westmoreland County (Greenbush) court-house, Pennsylvania, and an addition to the Marshall Field store in Chicago.

The American Stone Company's quarry is at North Jay, on the east side of the same hill on which the quarry above described is located. Address, Pierce V. C. Miller, secretary American Stone Company, 49 Wall street, New York.

The granite is identical with that of the Maine and New Hampshire Granite Corporation's quarry. (Specimen 118, *a*.)

The quarry measures about 300 feet from north to south by 200 feet east to west and is of varying depth. A little occasional pumping is necessary for drainage. Stripping, up to 8 feet of till.

Rock structure: An undulating flow structure like that in the previously described quarry, but with a northerly pitch of 10° to 40°, occurs in the northern part of quarry. The sheets are from 6 inches to 3 feet thick and dip 5°–10° E. Vertical joints strike N. 65°–70° E.; also N. 75°–80° W. The latter form a discontinuous heading in middle of quarry. Coarse pegmatite dikes up to 2 feet thick have courses of N. 60° E., north to south, and N. 20° E.

The plant consists of 3 derricks and 3 engines, 4 steam drills, 2 pumps, and 1 gas engine for same.

Transportation is effected by gravity to railroad seven-eighths mile distant.

This quarry produced the stone for all but the basement of Senator W. A. Clark's residence on Seventy-seventh street and Fifth avenue, New York. It is now idle, but not abandoned.

HANCOCK COUNTY.

The granite quarries in Hancock County are in the towns of Bluehill, Brooksville, Dedham, Franklin, Long Island, Mount Desert, Sedgwick, Stonington, Sullivan, Swans Island, and Tremont.

The White quarry, in the town of Bluehill, 1¼ miles east of Bluehill village. Operator, The White Granite Company, West avenue and Newton Creek, Long Island, N. Y.

The granite (specimen 36, *a*) is a biotite granite of medium-gray, slightly bluish color and of coarse (on the medium side) even-grained texture. The feldspars measure as high as one-half inch, and some of them a little over. The rock consists, in descending order of abundance, of potash feldspar (microcline and orthoclase), smoky quartz, soda-lime feldspar (oligoclase), and black mica (biotite),

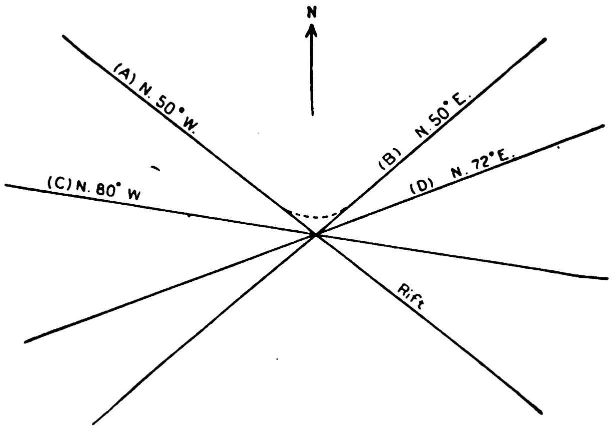

FIG. 7.—Structure at White quarry, Bluehill. The rectangular joint is shown by the dotted line.

together with accessory zircon and magnetite. The feldspar is slightly bluish. The contrast in shade between the polished and rough surface is marked, but the mica plates are sufficiently large and numerous to prevent a perfect polish. Although the texture of this stone is coarsish, it is sufficiently fine to be well adapted for fluted columns and capitals. A test of its compressive strength made at the United States Arsenal at Watertown (test No. 9087, 1893) gave an ultimate strength of 29,420 pounds per square inch, the pressure being applied at right angles to the rift. A similar test made by the engineering department of the School of Mines of Columbia University, in New York, gave an ultimate strength of 29,681 pounds.

The quarry, opened about 1855, measures 300 by 350 feet and from 15 to 45 feet in depth. The drainage that is not required for the boilers is effected by a channel to the harbor. There is no stripping.

Rock structure: The striking geological feature is the rectangular curved joint described on page 39 and shown in Pl. VI, *B*. The sheets are from 3 to 10 feet thick and dip from 10° to 15° W. and SW. The joint courses are shown in fig. 7. Joints A recur every 100 feet and form a heading at right of curved joint, as shown in Pl. VI, *B*. The rift is vertical, with a course N. 50° W., not very pronounced. There are small dikes and thick lenticular knots of very fine grained bluish-gray aplite. Dark-gray knots measure up to 10 by 4 inches. Sap is confined to the upper sheets, and does not exceed 2 inches in width. There are no rust stains.

The plant consists of 3 polishing machines, 3 hoisting engines, 3 derricks, and 1 steam drill.

Transportation is effected by team to docks, one-third mile off.

The product is used for buildings and monuments, and the waste goes into paving blocks. The chief market is New York. Specimen buildings: Woman's Hospital, in New York; Mercantile Trust Company's and Caledonia Insurance Company's buildings, in St. Louis. Contracts in 1905: Part of extension to House of Representatives; part of District of Columbia municipal building; First Day and Night Bank, New York; Delamar and Brokaw residences, New York; chemical laboratory of Pratt Institute, Brooklyn, N. Y.; chemical laboratory of Stevens Institute of Technology, at Hoboken, N. J., and a fountain with a large monolithic bowl for Deep River, Conn.

The Bluehill Granite Company's quarries are 1½ to 2 miles east of Bluehill village. The company is no longer in existence. The property is now owned by L. D. Willcutt & Son, 166 Devonshire street, Boston, but the quarries are not operated.

The granite is identical with that of the White quarry.

The quarries consist of three openings, one south of the White quarry, near the harbor; another south-southeast of that quarry, about 150 feet square and from 10 to 30 feet deep, and the third about one-half mile east of White quarry and 100 feet above it. This opening, known as the "doorstone quarry," is about 200 feet square and from 5 to 10 feet deep.

Rock structure: At the second opening the sheets are from 1 to 10 feet thick and undulate horizontally. At the third they are thinner, but have the same attitude. At the second opening a granite dike (described on p. 46) 18 inches thick strikes N. 55° E. and dips 80° NW. A joint and a heading strike N. 80° E. and dip 90°. At the third opening a vertical heading strikes N. 40° E. and a vertical joint strikes N. 70° W.

The product: The Eastport, Me., post-office and part of the Pittsburg, Pa., post-office and the Washington, D. C., Loan and Trust Company's building, corner of F and Ninth streets, are of granite

from the first two of these quarries. The product of the third was used only for doorsills, " platforms," and paving blocks.

The Chase granite quarry is in the town of Bluehill, 3 miles east of Bluehill Village, and north of Woods Point. Operator, Chase Quarries Company, 11 Broadway, New York. The quarries are not in operation at present.

The granite (specimen 38, *a*) is a biotite granite of medium to light-gray shade and coarse, even-grained texture, the feldspars measuring up to 0.8 inches in length. It consists, in descending order of abundance, of potash feldspar (microcline and orthoclase), smoky quartz, soda-lime feldspar (oligoclase), and black mica (biotite), with accessory magnetite. The feldspars are milky white with a slight bluish tinge. The contrasts between the feldspar, quartz, and biotite are marked, more so than in the White quarry stone, because the feldspar is whiter, the quartz more smoky, and the biotite a trifle coarser. The following chemical analysis of this granite, made in 1896 by Ricketts and Banks, of New York, is inserted here merely for reference:

Analysis of granite from Chase granite quarry, near Bluehill, Me.

SiO_2 (silica)	73.02
FeO (ferrous oxide)	2.59
Al_2O_3 (alumina)	16.22
MnO (manganous oxide)	Trace.
CaO (lime)	0.94
MgO (magnesia)	Trace.
K_2O (potash)	3.42
Na_2O (soda)	3.60
S (sulphur)	None.
Loss and undetermined	0.21

The same firm also made a test of this granite (test No. 16606, 1899) which showed that it has an ultimate compressive strength of 23,400 pounds per square inch.

The quarry, opened in 1872, consists of several openings on the top and eastern slope of a hill rising 220 feet above the sea in a distance of three-fourths mile. Drainage is effected by occasional use of siphon and pump.

Rock structure: The sheets are up to 8 feet thick and either lie horizontal or dip at a low angle. Vertical joints strike N. 50° W. and N. 40° E. The rift is vertical, with a north strike. There are some small dikes of aplite and dark-gray knots. Sap occurs in the upper sheets to a thickness of several inches. In one of the openings the stone has occasional light rust spots half an inch in diameter, which are due to the oxidation of some ferruginous mineral in very minute particles.

The plant consists of 9 derricks and 5 hoisting engines, 1 cable

engine, 1 locomotive crane, 1 compressor, 4 steam drills, 3 pneumatic plug drills, 2 surfacers, and 2 pumps.

Transportation is effected by a cable road 1,400 feet long from the main quarry to the cutting shed and by locomotive and track, 650 feet more, from shed to dock.

The product is used for buildings. Specimen buildings made of this granite are the New York Stock Exchange, Lying-in Hospital, Manhattan Trust Building, and Grand Union Hotel, Forty-second street, New York, the General Thomas monument, and the trimmings to the Bureau of Engraving and Printing, Washington, D. C.; the League Island dry dock, and the post-office at Harrisburg, Pa. Paving blocks are a by-product.

The Chase Quarries (*monumental granite*) are in the town of Bluehill. About 350 feet east of the upper opening of the Chase quarries is an area not less than 200 feet square, of a medium bluish-gray fine-textured, porphyritic biotite-muscovite granite (specimen 39, *a*). The particles range in general size from 0.07 to 1.1 mm. in diameter, averaging about 0.37 mm. The isolated feldspars measure up to one-fourth inch across. The minerals, arranged in descending order of abundance, are potash feldspar (orthoclase and microcline), smoky quartz, soda-lime feldspar (oligoclase), black mica (biotite), and white mica (muscovite), with accessory magnetite. The feldspars are bluish gray. They have considerable intergrown quartz and the rock is generally harder than the adjacent granite, which it probably traverses as a large dike. It has been quarried occasionally by the company for local monumental use.

The Collins Granite Company's quarry, in the town of Bluehill, three-fourth mile east of East Bluehill, has not been operated since 1888 or 1889.

The granite (specimen 40, *a*) is a biotite granite of medium-gray shade and porphyritic texture, with feldspar crystals up to one-half inch in length, in a fine-textured matrix in which many particles measure down to 0.05 to 0.25 mm. The minerals, in descending order of abundance, are potash feldspar (microcline and orthoclase), smoky quartz, soda-lime feldspar (oligoclase), generally altered to kaolin and a white mica, and black mica (biotite), with a very little muscovite.

The quarry is 150 by 60 feet and from 15 to 30 feet deep.

Rock structure: The sheets lie flat and are up to 10 feet thick. The joints strike N. 5° E. and N. 60° W., with steep or vertical dip. The first set is spaced 20 feet and the other forms a heading.

Transportation: The stone was carted two-fifths mile to the cutting buildings and dock.

Part of the Pittsburg, Pa., post-office was built of material from this quarry.

The Howard quarry is in the town of Bluehill, 1 mile southeast of top of Bluehill and 1¼ miles northeast of Bluehill village. Owner, William M. Howard, Bluehill.

The granite is a biotite granite like that of the White quarry.

The quarry is about 50 feet square and from 5 to 15 feet deep.

The sheets, 8 feet thick, dip 40° N. The rift is vertical with a strike of N. 10° W. Sap is 3 inches thick on each side of sheets.

The plant consists of one hand derrick. The stone is carted one-half mile, where it is cut and polished. The product is used locally for monuments.

Some of the stone of the gate house to High Bridge, in New York, came from this quarry, and also several soldiers' monuments.

The Bucks Harbor quarries, Bucks Harbor, South Brooksville, are operated by the Bucks Harbor Granite Company.

The granite (specimen 46, *a*) from opening one-half mile southeast of South Brooksville, is a biotite granite of light grayish-buff color with conspicuous black mica, and is of coarse (inclining to medium) even-grained texture. It consists, in descending order of abundance, of a light cream-colored potash feldspar (microcline and orthoclase), smoky quartz, a milk-white soda-lime feldspar (oligoclase), and black mica (biotite) with accessory magnetite. The oligoclase is partially altered to kaolin and a white mica. A little pyrite was found at the quarry.

The granite (specimen 47, *a*) from opening one-fourth mile northeast of South Brooksville, is of medium-gray shade, with conspicuous black mica and coarse, even-grained texture, and consists, in descending order of abundance, of a very light gray potash feldspar (microcline and orthoclase), slightly smoky quartz, a little soda-lime feldspar (oligoclase), and black mica (biotite). Both of these granites are bright from the contrasts of their minerals.

The quarries consist chiefly of two openings—one formerly operated by the Wilson Granite Company, and lying one-half mile southeast of the village, measuring 200 feet by 100 feet, and from 5 to 20 feet in depth; the other, one-fourth mile northeast of the village, is about 200 by 100 feet, and from 5 to 10 feet deep.

Rock structure: The sheets at these quarries are from 2 to 8 feet thick and are either horizontal or dip 10°-15° W. Joints at the first opening strike N. 40° W., dip 75° S. W., and recur at intervals of 15 feet or more; also N. 50° E., dipping 75° S. 50° W. to 90°. The rift is vertical, striking N. 30° E. The sap is confined to the uppermost sheets.

The plant consists of 3 derricks and 1 hoisting engine.

Transportation: The company owns two granite wharves, which afford 12 feet of water at low tide.

The product of these quarries is adapted to building purposes. In 1905, pending a reorganization of the company or an enlargement of its capital, the quarries had not yet resumed operations.

The Westcott quarry is at Bucks Harbor, in the town of Brooksville, about three-fourths mile southeast of South Brooksville village. Owners, Maine Coast Granite Company, South Brooksville. The granite of this quarry is said to be like that of the more eastern quarry of the Bucks Harbor Granite Company, which is very near it, and to have been used for pillars in the bridge over the Mississippi at St. Louis.

The Maine Lake Ice Company's quarry lies 500 feet north of the company's dock. It is operated by Foster and Sargent, of Sargentville, for paving blocks, but is now idle.

The granite (specimen 43, *a*) is a biotite granite of medium to light gray shade and coarse even-grained texture, with slightly bluish milk-white feldspars up to an inch in length. It consists of these minerals, in descending order of abundance: A potash feldspar (microcline and orthoclase), rather dark smoky quartz, soda-lime feldspar (oligoclase), black mica (biotite), and accessory zircon. The oligoclase is considerably altered to a white mica. The contrasts in this granite are more marked than in that of specimen 47, *a* (p. 88), for the quartz is darker. It was found to be hard in working.

The quarry measures about 200 by 30 feet and 10 feet in depth. The sheets are up to 5 feet thick and lie flat or dip 10° N. Vertical joints with headings strike N. 67° E. and N. 67° W. The rift is vertical, and its course is N. 60° W.

There is a track 500 feet long to the dock.

Herrick's quarries, in the town of Brooksville, consisting of several small openings, about one-third mile northwest of "Herrick" post-office, worked by E. H. Herrick for paving blocks, curbing and rough stone, give employment to three men. The stone (specimen 44, *a*) is a biotite granite of medium-gray color and medium even-grained texture.

Sargent's quarry, in the town of Brooksville, is a small opening, less than one-fourth mile northeast of Herrick's, belonging to Henry W. Sargent, but not worked in 1905. The stone is a gray even-grained coarse-textured granite, resembling that of the Maine Lake Ice Company's quarry. In contact with it is also one of slightly finer texture, but with poor contrasts (specimen 45, *a*).

The Brown quarry is in the town of Dedham, 1½ miles east of Holden station (East Holden post-office) on the Maine Central Railroad, on the northeast side of a hill reaching an altitude of 840 feet above sea level and having a northwest and southeast axis. Operator, David Brown, East Holden.

The granite (specimen 108, *a*) is a biotite granite of dark-gray matrix with light-grayish feldspars and of very coarse porphyritic texture, with some evidence of distortion and crushing of its feldspars. These measure up to 1½ inches in diameter and the black mica up to three-tenths inch. The feldspars are generally twinned and often of oval or roundish outline. The rock consists, in descending order of abundance, of potash feldspar (orthoclase and microcline) smoky quartz, soda-lime feldspar (oligoclase) and black mica (biotite), together with accessory zircon, apatite, and secondary magnetite and chlorite. The quartz contains needles of rutile (?). The orthoclase crystals contain zonally arranged quartz grains and biotite scales and are sometimes thinly rimmed with oligoclase or intergrown with it. Many small grains of quartz in the matrix indicate crushing. The oligoclase is partially altered to kaolin and a white mica. The rock takes a fine polish, but the durability of the polish under outdoor exposure is doubtful, owing to the large size of the mica scales.

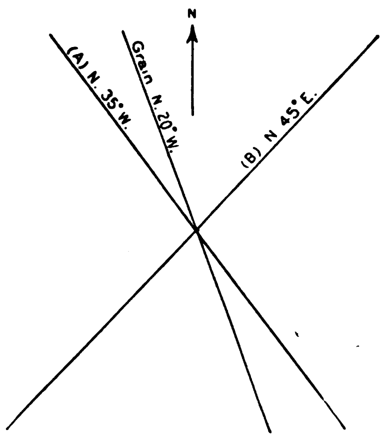

FIG. 8.—Structure at Brown quarry, Dedham.

The quarry, opened in 1892, is 200 feet north-northwest to south-southeast by 20 feet across and from 4 to 9 feet deep. The stripping consists of drift up to 6 feet thick, but in places there is none.

Rock structure: The sheets, from 2 to 6 feet thick, dip 15° SSE. Joint courses are given in fig. 8. A recur at intervals of 100 to 200 feet; B at intervals of 75 feet or more. The rift is horizontal. Aplite dikes, from 1 to 4 inches thick, cross the grain at high angle. No knots are in sight. Sap, from 1 to 2 inches thick, is confined to the topmost sheet.

The plant consists of 5 derricks, worked by horses and oxen, and 1 engine.

Transportation is had by cartage 1½ miles to Holden station, where the cutting shed is.

The product is used for bridge work. Contract in 1905: Maine Central Railroad bridge and station improvements at Bangor.

The Robertson & Havey quarry in the town of Franklin, owned and operated by Robertson & Havey; address, North Sullivan.

The granite (specimen 71, *a*) is a biotite granite of medium-gray shade and of coarse (inclining to medium), even-grained texture, with whitish feldspars up to one-half inch in diameter, consisting,

in descending order of abundance, of potash feldspar (orthoclase and microcline), slightly smoky quartz, soda-lime feldspar (oligoclase), and black mica (biotite), with accessory magnetite and pyrite. The slight contrast between the shade of the quartz and that of the feldspar and the small size of the biotite scales produce a general lack of brilliancy in the rock.

The quarry, opened in 1892, measures 300 feet from north to south by 300 feet from east to west, and from 5 to 15 feet in depth. It is drained by two siphons (2½ and 3½ inch pipes) 800 and 1,000 feet long. The stripping consists of 3 to 4 feet of loam and bowlders.

Rock structure: The sheets, from 2 to 8 feet thick, are horizontal, but on the west side dip 10° W. The courses of joints and dikes are given in fig. 9. Joints A recur at irregular intervals. The rift is

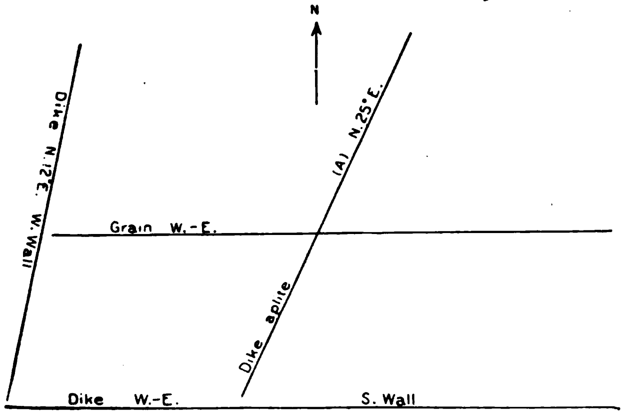

FIG. 9.—Structure at Robertson & Havey quarry, Franklin.

horizontal and the grain is vertical, striking east-west. Aplite dikes measure from 2 to 8 inches in width, and the granite for about a foot on each side of them is close jointed. Knots are rather abundant and up to 2 feet across. The north-south joint face carries some pyrite. Sap measures from 2 to 3 inches in width along the sheets. No rust spots were detected. A 1-foot diabase dike, with its rim altered to epidote, forms the west wall of quarry, and a 2½ to 3 foot dike forms the south wall. For a space of 10 feet on each side of this dike the shade of the granite has been changed to a dark gray, and the rock is filled with close joints that dip at low angles. The microscope fails to reveal the nature of this change, but shows that the quartz particles and some of the feldspars are crossed by more or less parallel cracks, from 0.25 mm. to 1.25 mm. apart.

The plant consists of only one derrick and the siphon pipe.

Transportation is effected by cartage 1¾ miles to dock in bay.

The product is used for curbing, both straight and circular, and

for paving blocks and "random" stone. The principal markets are Boston, New York, and Philadelphia.

The Bragdon, Fernald, & Gordon quarry is in the town of Franklin. The firm's address is Franklin.

The granite is a biotite granite of medium-gray shade and medium, even-grained texture like that of the Crabtree & Havey quarry (specimen 69, *a*) in Sullivan (p. 110). Molybdenite was found in it.

The quarry measures 300 feet from north to south by 150 feet from east to west and from 10 to 20 feet in depth, and is drained by a 3-inch siphon pipe 600 feet long.

Rock structure: The sheets, from 2 to 6 feet thick, dip 10° to 15° W. Joint and dike courses are shown in fig. 10. Joint A recurs 150

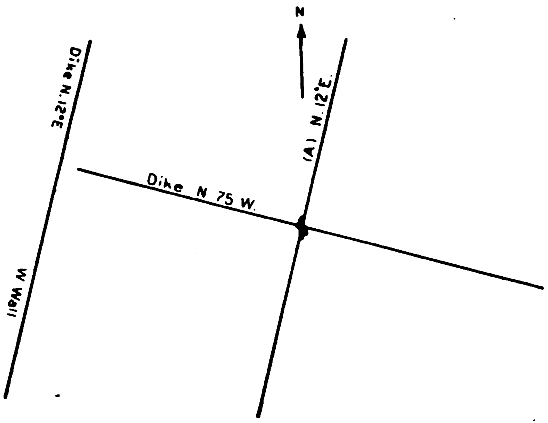

FIG. 10.—Structure at Bragdon, Fernald, & Gordon quarry, Franklin.

feet away. The north-south dike is 6 inches thick and tapers out. The other is up to 12 inches thick. Knots measure up to 12 inches across.

The plant consists of 3 derricks, worked by horses, and of 600 feet of siphon pipe.

Transportation is effected by cartage of 2 miles to wharf.

The product is used for curbing (both straight and circular), paving blocks, and "random" stone. The markets are Philadelphia, New York, and Boston.

The Alonzo Abbott quarry is in the town of Franklin. Address, Alonzo Abbott, Hancock, Me.

The granite is a biotite granite of medium-gray shade and coarse (inclining to medium), even-grained texture, identical with that of specimen 71, *a*, Robertson & Havey (p. 90).

The quarry, opened about 1885, measures 200 feet from east to west by 150 feet from north to south and from 2 to 8 feet in depth, and is drained by siphoning. The stripping consists of 3 feet of loam and bowlders.

Rock structure: Sheets from 2 to 8 feet thick dip both east and west at 5°–10°. Vertical joints with a N. 25° E. course recur at irregular intervals. The rift is horizontal.

The plant consists of 2 derricks, worked by horses, and a siphon pipe.

Transportation is effected by cartage of a mile to wharf.

The product consists of curbing, flagging, paving, and random, and goes to Boston, New York, and Philadelphia.

The T. M. Blaisdell quarry is in East Franklin, 1 mile above the head of navigation. Address, T. M. Blaisdell, East Franklin.

The granite (specimen 76, *a*) is of a darkish medium-gray shade and medium even-grained texture, with feldspars up to one-fourth inch in length, and consists, in descending order of abundance, of

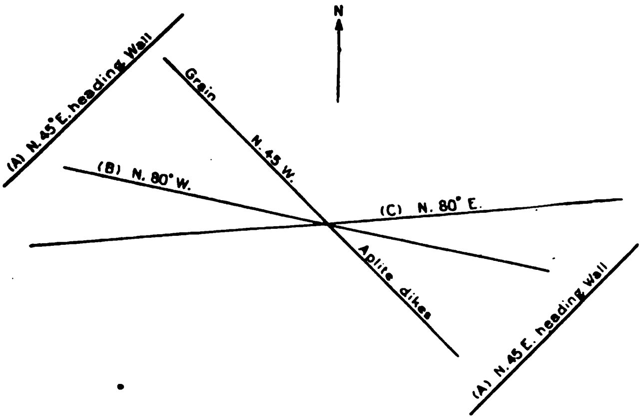

FIG. 11.—Structure at T. M. Blaisdell quarry, East Franklin.

potash feldspar (microcline and orthoclase), slightly smoky quartz, lime-soda feldspar (oligoclase to oligoclase-albite), black mica (biotite), together with accessory magnetite and zircon. The effect of the slightly bluish gray color of the feldspar and the light smokiness of the quartz is to prevent any contrast of shade between these two minerals and also to darken the general color of the stone.

The quarry, opened about 1875, measures 200 by 300 feet and is of varying depth. The working face on the north is 53 feet high. Neither drainage nor stripping is required.

Rock structure: The sheets, from 2 to 13 feet thick, dip 10° NE. Owing to compressive strain, on the removal of load in quarrying, the bottom sheet rises half an inch from the underlying one. The joint courses are shown in fig. 11. A forms a heading on the northwest and southeast sides. C dips in places 45° N. The rift is horizontal and grain vertical, trending northwest-southeast. Several parallel dikes of aplite up to 2 inches thick dip southwest at a

low angle. In one 5-foot mass there are five of these. Sap is confined to the upper sheets. Black knots measure up to 8 inches across.

The plant consists of 4 derricks, worked by horses or men.

Transportation is effected by carting a few hundred feet and loading on a lighter, which is propelled by poles a mile to a wharf where the blocks are laden onto schooners by means of a derrick. It is proposed, however, soon to propel the lighter by an engine, by which also the stone will be hoisted onto the schooners.

The product is used for curbing, paving, bridges, docks, and "random," and finds market in Boston, Philadelphia, New York, and Washington.

The W. B. Blaisdell & Company quarry is in the town of Franklin, on the southeast side of Sullivan River. Address, Franklin, Me.

The granite (specimen 78, *b*) is a biotite granite of medium-gray

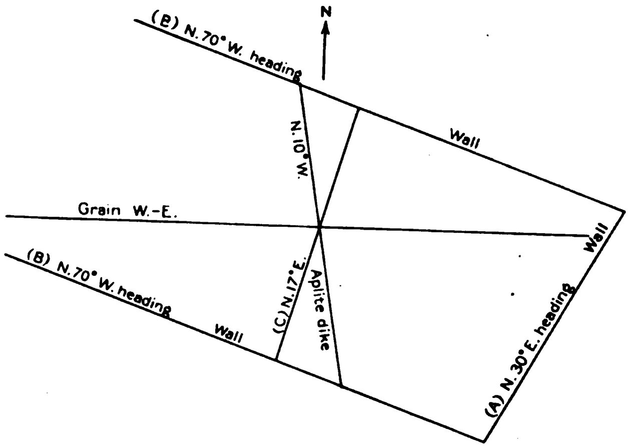

FIG. 12.—Structure at W. B. Blaisdell quarry, East Franklin.

shade and medium (inclining to coarse) even-grained texture, consisting, in descending order of abundance, of potash feldspar (microcline and orthoclase), smoky quartz, soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite, zircon, apatite, and secondary epidote and chlorite. The oligoclase is partially altered to a white mica. The feldspars are grayish, and are therefore of almost the same shade as the quartz, which deprives the rock of marked contrasts. It is a little lighter than specimen 76, *a*, of the T. M. Blaisdell quarry, and is said to be a little softer. Mr. E. C. Sullivan has tested the granite (78, *b*) with warm dilute acetic acid at the chemical laboratory of the United States Geological Survey and finds that it contains 0.15 per cent of CaO (lime), much MgO (magnesia), and 0.104 per cent of CO_2 (carbon dioxide).

If all the CO_2 were allotted to CaO it would give 0.24 per cent of $CaCO_3$ (lime carbonate) as the content in the granite.

The quarry, opened about 1875, measures 300 by 250 feet, and from 15 to 35 feet in depth. It is drained by siphoning. The stripping consists of 3 feet of clay and bowlders.

Rock structure: The sheets are from 6 to 7 feet thick and generally dip northwest at low angles. There is some "toeing in," owing to the overlapping of lenses. Joint and vein courses are given in fig. 12. A forms a heading on the east side of quarry; B is on the north and south sides and is coated with lime carbonate (calcite), as described on page 41. The heading on the south has four joints 3 feet apart. C is coated with pyrite, and hence is called by workmen the "iron seam." The rift is horizontal and grain vertical east-west. The sap measures from 1 to 3 inches in thickness. There are some knots up to 6 inches across.

The plant consists of 2 derricks and siphon pipes.

Transportation is effected by "lifters" drawn by horses 1,000 feet to schooners at dock.

The product is used for curbing (both straight and circular) and paving in Boston, Philadelphia, and New York.

F. Bradbury & Sons quarry is in West Franklin, near north end of Grape Pond; address, West Franklin.

The granite (specimen 77, *a*) is a biotite granite of dark-grayish, slightly purplish color, of very coarse, somewhat porphyritic texture, with feldspars up to an inch in diameter and black mica plates up to one-tenth inch. It consists, in descending order of abundance, of a grayish-purplish potash feldspar (orthoclase and microcline), smoky quartz, yellowish-white soda-lime feldspar (basic oligoclase), and black mica (biotite), together with accessory magnetite, apatite, zircon, and secondary chlorite. Many of the grayish-purplish potash feldspars are rimmed with the yellowish oligoclase, and are also intergrown microscopically with a plagioclase feldspar and with quartz. This granite is very striking in the contrasts of its minerals. Its quartz and feldspars take a high polish, but the large biotite scales are not favorable to the durability of the polish under outdoor exposure.

The quarry is triangular in area, each side of the triangle measuring about 75 feet, and its depth reaches in places 15 feet, which is the height of the working face.

Rock structure: The sheets are 10 feet thick and about horizontal. Joints striking N. 70° W. and dipping high east recur at intervals of 5 feet or more. There are a few knots.

The plant consists of 2 derricks.

Transportation is effected by cartage to railroad about 900 feet away.

The product has been thus far used for culverts and similar structures on the Maine Central and Washington County railroads.

The Black Island quarries are in the northeastern part of Black Island, which lies south of Mount Desert, in the town of Long Island. Operators, Black Island Granite Company, J. E. Dutton, president, 42 East Twenty-third street, New York.

The quarries, opened in 1892, consist of two openings. The upper one, about one-fourth mile south of dock at northeastern corner of island, measures 500 by 300 feet and from 10 to 40 feet in depth, and the lower one, known as the "Redcliff," a little south of the dock, is about 100 feet square. There is no drainage to contend with.

The granites taken from these two openings differ. Specimen 31, *a*, from the upper quarry, is a biotite granite of pale pinkish-gray color and medium (inclining to coarse) even-grained texture, consisting, in descending order of abundance, of potash feldspar (microcline and orthoclase), smoky quartz, soda-lime feldspar (oligoclase), and very little black mica (biotite), together with accessory titanite and magnetite. Both feldspars are light pink. The potash feldspar is sometimes rimmed with oligoclase. The latter is often partially altered to kaolin and a white mica. The rock presents but faint contrasts of color and, owing to the small quantity of its mica, must needs take a very fine polish.

The granite (specimen 39, *a*) of the Redcliff quarry is a biotite granite of grayish-pink color and medium (inclining to coarse) even-grained texture, consisting, in descending order of abundance, of potash feldspar (microcline and orthoclase), smoky quartz, soda-lime feldspar (oligoclase), and very little black mica (biotite), together with accessory titanite, magnetite, and zircon. Both feldspars are pinkish. The oligoclase is largely altered to kaolin and a white mica. Its small content of mica must make this granite susceptible of high polish.

Rock structure: At the upper quarry the sheets, from 8 inches to 5 feet thick, are horizontal, with minor undulations. Vertical joints strike N. 70° W., recurring at intervals of 100, 200, and 250 feet. The rift is parallel to these, but feeble. Sap, 3 inches thick, is confined entirely to the upper sheets. At the Redcliff quarry the sheets, up to 6 feet in thickness, bend over from the horizontal to 25° N. and NE. Vertical joints, striking N. 77° E., recur at intervals of 50 feet. Another set, striking N. 35° E., abounds at the sides of the quarry, but is scarce in center. Joints of this strike are numerous along the north shore of the island. The rift is vertical, with a N. 77° E. course.

The plant consists of 3 derricks, 2 engines, and 3 steam drills at the upper quarry; 1 derrick at the wharf; 2 derricks and engine and polisher run by the same at the lower quarry.

Transportation is effected by a track and cable one-fourth mile long from upper quarry to the wharf and a short one from the lower quarry.

The product of the upper quarry is used for buildings, and its thin sheets are used for paving. That of the Redcliff quarry is used particularly for monuments and columns. The markets are Boston, New London, New York, and Baltimore. A contract for the Park Building, in Brooklyn, N. Y., was being executed in 1905.

The McMullen quarry is in the town of Mount Desert, southeast of village of "Hall Quarry," and four-fifths of a mile north of Robinson Mountains. Operators, Arthur McMullen & Co., Park Row building, New York. (In hands of a receiver in August, 1905.)

The granite (specimen 55, *aa*) is a biotite granite of general light-grayish buff color and coarse (inclining to medium), even-grained texture, consisting, in descending order of abundance, of buff-colored potash feldspar (orthoclase intergrown with plagioclase), smoky quartz, milk-white soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory apatite and a little secondary calcite within the oligoclase. The contrasts resulting from the different shades and colors of the four minerals are attractive and must come out still more strongly on the polished surface. Mr. E. C. Sullivan has examined this granite at the chemical laboratory of the United States Geological Survey and finds that it contains 0.014 per cent of CO_2 (carbon dioxide) and that warm dilute acetic acid dissolves traces of CaO (lime) and MgO (magnesia). This percentage of CO_2, if all allotted to CaO, would imply the presence of 0.03 per cent of $CaCO_3$ (lime carbonate). The microscope also shows the presence of a carbonate in very minute quantity.

The quarry, opened in about 1880, measures 250 feet from north to south by 250 from east to west and attains a depth of 50 feet at the west side. A little pumping is necessary at times to drain it. The stripping consists of 3½ feet of drift and bowlders.

Rock structure: The sheets are from 2 to 12 feet thick and dip from 5° to 10° north to south and east. They are faulted along some of the N. 25° W. joints, resulting in a toeing in of the sheets, which necessitates quarrying from west to east—that is, toward the hade of the faults, as shown in fig. 13. The courses of the joints are shown in the same figure. A forms a heading on the west, dipping 80° W.; B, dipping 65° S., forms a heading on the north and recurs at middle of quarry; C, dipping 75° to 80° NW., forms a heading on the south and recurs at irregular intervals. The rift is horizontal and the grain strikes about east-west. Sap along some of the sheets is 3 inches thick and exceptionally 18 inches. The granite along joints A and B for the space of a foot is bright reddish. (See p. 52.) The faces are

greenish, probably from presence of chlorite and epidote. Dark-gray knots measure up to 6 inches in diameter.

The plant consists of 12 derricks, 12 hoisting engines, 1 hanging electric crane (capacity 15 tons), 1 locomotive, 2 compressors (capacity 750 and 1,400 cubic feet per minute), 5 steam drills, 25 pneumatic plug drills, 18 surfacers, and 36 pneumatic hand tools.

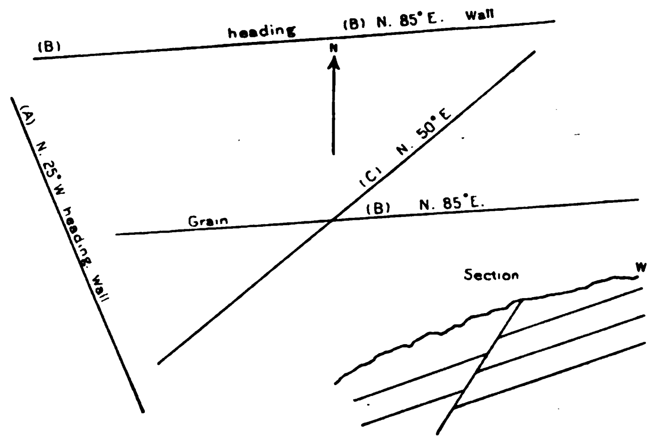

FIG. 13.—Structure at McMullen quarry, Mount Desert Island. The section shows the "toeing in" of sheets, probably by faulting along the joints.

Transportation is effected by track to wharf, 800 feet off, which is accessible to schooners of 20 feet draft.

The product is used for construction in New York and Washington. Specimen buildings made of this granite are the United States mint in Philadelphia, the basement of the New York custom-house, and the new bridge over the Potomac at Washington. Contracts in 1905: Brooklyn anchorage to Manhattan Bridge.

The Campbell & Macomber quarry is in the town of Mount Desert, one-half mile north of top of Robinson mountain, at its foot, and two-fifths of a mile south of "Hall Quarry" village. Office address, Hall Quarry, Me.

The granite (specimen 56, *a*), known commercially as "Somes Sound Pink," is a biotite granite of light pinkish-gray color and medium, inclining to coarse, even-grained texture, consisting, in descending order of abundance, of a delicate pink potash feldspar (orthoclase, with very little microcline), smoky quartz, milk-white soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite, zircon, and apatite. It takes a fine polish, This stone differs from the McMullen quarry stone in the tint of its orthoclase.

The quarry, opened in about 1880, measures 150 by 200 feet by 20

feet in depth. Drainage is effected by siphoning and pumping in spring and fall. No stripping.

Rock structure: The sheets, from 2 to 6 feet thick, dip 10° to 15° E., and exceptionally are thinner at the bottom than the top of quarry. Joint and dike courses are shown in fig. 14. All are vertical. B forms a heading at the south side, C one at the north. The rift is horizontal and grain N. 75° E. A diabase dike, 2½ feet wide, tapering toward the north, occurs at the west side of quarry. This is described on page 48. There are a few knots, but sap does not occur.

The plant consists of 5 derricks, 1 hoisting engine, 1 25-horsepower compressor, 2 pneumatic plug drills, 1 surfacer, 12 pneumatic hand tools, and 1 pump.

Transportation is effected by cartage of 1,600 feet to wharf on Somes Sound.

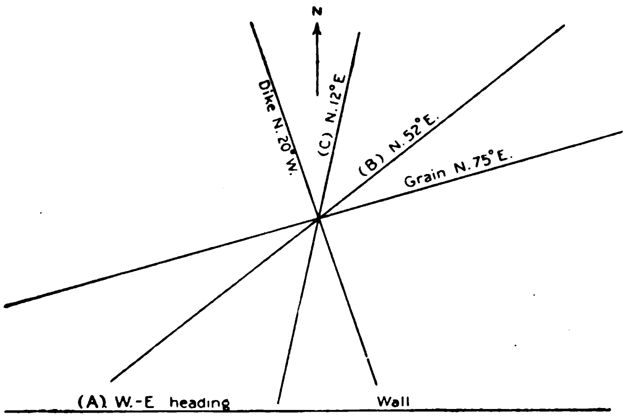

FIG. 14.—Structure at Campbell & Macomber's quarry, Mount Desert Island.

The product is used for buildings, chiefly in New York. Specimen buildings: The Crocker residence at Darlington, N. J.; the Danforth Library at Paterson, N. J.; the First National Bank at Baltimore, Md. Contract in 1905: The Phœnix National Bank at Hartford, Conn.

The Snowflake quarry, on Mount Desert, about one-fourth mile northwest of Hall Quarry village, is operated by the Allen Granite Company. Address, M. L. Allen, Mount Desert, Me.

The granite (specimen 58, *a*) is a biotite granite of medium-gray shade and fine texture, with porphyritic pinkish feldspars up to 0.4 inches in diameter. It consists, in descending order of abundance, of pinkish potash feldspar (orthoclase), smoky quartz, white translucent soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite. The orthoclase is intergrown with a plagioclase.

The quarry is about 200 feet square and from 5 to 10 feet deep.

Rock structure: The sheets, from 6 inches to 3 feet thick, are horizontal. Joints forming a heading on east side strike N. 20° W. and dip 75° W. A diabase dike, 6 to 10 inches thick, with course N. 20° W., traverses the entire quarry.

The product is confined to paving blocks, which are carted about one-half mile to the wharf.

The Allen quarry belongs to the same concern as the "Snowflake," and lies one-fourth mile east of it. It is no longer worked. The granite closely resembles that of the "Snowflake." The sheets are from 6 inches to 3 feet thick. Pl. VIII, *B*, shows the sheets crossed by a diabase dike, which has a N. 15° W. course, and is faulted in two directions. (See p. 47.) There are geodes of pink feldspar, quartz, and epidote in the granite.

The Babbadge quarry, on Mount Desert, about one-third mile southwest of Hall Quarry village, is operated by Seth Babbadge; address, Hall Quarry post-office. The granite is a coarse-grained biotite granite. The quarry is 50 by 50 feet and from 5 to 10 feet deep. The sheets, which are up to 6 feet thick, lie horizontal. A diabase dike on the east side strikes N. 20° W. There is one derrick. The product is sold to the McMullen Company.

The Richardson Brothers quarry, on Mount Desert, lies nearly one-half mile southwest of Hall Quarry village; address, Hall Quarry post-office. The rock is a coarse biotite granite. The quarry is 100 feet square and 5–10 feet deep. The sheets are spaced from 1 to 6 feet. There is one derrick. The product is also sold to the McMullen Company.

The Fernald Brothers and Higgins quarry is on Mount Desert, one-fourth mile north of Sound, on the east side of Somes Sound; address, Mount Desert post-office.

The granite is a coarse biotite granite resembling that of the McMullen quarry. There are several small openings, first worked in 1888. The one worked in 1905 is 50 feet square and a few feet in depth. There is one derrick. The sheets are up to 6 feet thick. The product is all used for paving and is carted about one-fourth mile to wharf.

The Graves Brothers quarry is on Mount Desert, in the northern part of village of Northeast Harbor; address, Northeast Harbor. This quarry is worked only occasionally, for underpinning. It is mentioned here on account of the exceptional character of the stone among Maine granites, which (specimen 64, *a*) is a hornblende granite of general dark-gray color and medium even-grained texture, consisting, in descending order of abundance, of greenish-gray and pinkish potash feldspar (orthoclase and microcline), with inter-

grown soda-lime feldspar (oligoclase-andesine), smoky quartz, and dark-green hornblende, together with accessory magnetite, apatite, and secondary chlorite. The feldspar is largely altered to a white mica. A similar granite occurs also 1½ miles west-northwest of it, at the Carroll quarry, in the town of Tremont, at the south foot of Dog Mountain. (See p. 116.)

The quarry measures 100 by 50 feet and 10 feet in depth at the deepest point. The sheets are up to 6 feet thick and dip 5°–10° W. There is much discoloration.

The Sedgwick quarries consist of 6 small openings in the town of Sedgwick, about three-fourths mile northwest of Sedgwick village, operated by the W. G. Sargent Company, of Sargentville.

The granite (specimen 42, *a*) is a biotite granite of coarse to medium even-grained texture, like that of one of the Bucks Harbor quarries (specimen 46, *a*, p. 88), consisting of light cream-colored feldspars, smoky quartz, and black mica, all in marked contrast. The feldspars measure up to three-fourths inch in length and the biotite plates one-tenth inch.

The rift is vertical, with a strike of N. 22° W. The plant consists of 2 hand derricks. The product, consisting entirely of paving blocks, is carted 1¼ miles to the wharf at Sedgwick.

The Stonington quarries.—The granite industry which centers in Stonington is distributed over an area of about 4 miles square. (See map, fig. 15.) Some of the quarries are on Deer Isle, others are south of it, on Crotch Island, so named from the inlet which divides it, and the rest are on neighboring islets. Of the latter, however, only those on Moose, Green, and Spruce islands were in operation in 1905.

The southern half of Crotch Island, which measures about 1,500 feet from north to south, shows sheet structure very clearly. (See Pl. II, *B*.) The sheets slope off to the northwest and the southeast at angles of 10°, 15°, 20°, and 25° from its central part (140 feet above sea level), where they are horizontal. The east-west vertical joints are conspicuous from a distance. The Goss quarry has cut into the center of the arch and also on either side of it, while the Ryan-Parker quarry (Pl. III, *A*), on the south, is on the southeast slope of the sheets and of the hill. In the northern half of Crotch Island, at the lower quarry of the Sherwood Company, the coarse granites are in contact with a fine-textured one, which is also exploited. The contact line is vertical, but the sheets traverse both granites indifferently. The Stonington quarries, as will be seen from the descriptions, embrace several varieties of granite.

The Ryan-Parker quarry is on Crotch Island, in its southeastern part, at Thurlow Head. (See Pl. II, *B*, and fig. 15.) Operators,

Ryan-Parker Construction Company, Park Row building, 13–21 Park Row, New York.

The granite (specimen 20, *b*) is a biotite granite of lavender, medium-gray color and coarse, even-grained texture, consisting, in descending order of abundance, of very light lavender-colored potash feldspar (orthoclase and microcline), smoky quartz, milk-white soda-lime feldspar (oligoclase), and a little mica (biotite), rarely a plate

FIG. 15.—Map showing location of quarries about Stonington, Me. (Reduced from Deer Isle Sheet, Topographic Atlas U. S., U. S. Geol. Survey.)

of muscovite, together with accessory magnetite, titanite, zircon, and pyrite, partially altered to limonite. The potash feldspars measure up to 1 inch and many of them are twinned and intergrown with a plagioclase. The biotite plates do not exceed 0.1 inch across. The oligoclase is generally much altered to a white mica and kaolin.

Mr. E. C. Sullivan, of the United States Geological Survey, determined the presence in this granite of 0.044 per cent of CO_2 (carbon dioxide) and of 0.08 per cent of CaO (lime) and a little MgO (mag-

nesia) extractable with dilute acetic acid. To allot all the CO_2 to the CaO would give 0.10 per cent of lime carbonate in the granite.

The quarry, opened about 1880, measures about 700 by 300 feet, and from 20 to 75 feet in depth, averaging about 35 feet. (See Pl. II, *A*.) The drainage from its upper half flows seaward, but that from its lower half must be pumped after heavy rains. Water for steam purposes was brought in a "water boat" a mile from Stonington at an expense of $110 per month, but a well that was being bored in the granite near the shore was expected to yield a supply sufficient to save this large expenditure. Little or no stripping has been required.

Rock structure: The sheets vary in thickness downward, and dip from 20° to 25° SE. Joint courses are shown in fig. 16. A dips 80°

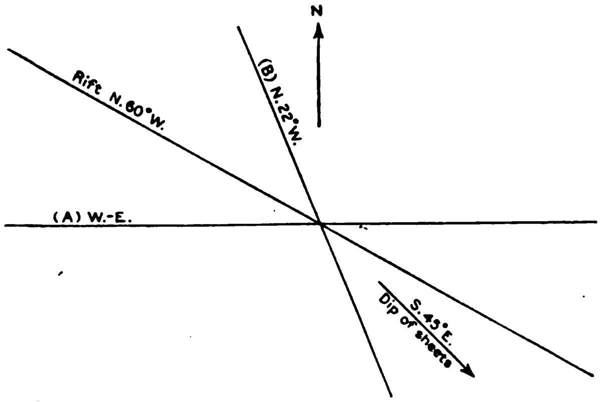

FIG. 16.—Structure at Ryan-Parker quarry, Crotch Island.

and forms a heading on the north, and B also forms one. Both A and B are infrequent. The rift is vertical and trends N. 60° W. Sap occurs from 6 to 12 inches on either side of joint B.

The plant consists of 9 derricks, worked by 9 hoisting engines; a traveling crane of 20 tons' capacity; one compressor of 900 cubic feet capacity per minute; 8 large pneumatic drills; a number of pneumatic plug drills; 4 surfacers; one lathe carrying stones 8 feet by 2 feet 6 inches; and two steam pumps.

Transportation to the wharfs is effected by means of gravity on tracks 75 and 100 feet long.

The product is used chiefly for massive construction and for buildings, and its market is New York, where the firm is engaged in building enterprises. Among the public structures made of this granite are the piers of the Blackwells Island bridge in New York. In 1905 this quarry was furnishing the stone for the retaining wall of the Riverside Drive in New York.

The Goss quarry is on Crotch Island, adjacent to and north of the Ryan-Parker quarry, on Thurlow Head. (See fig. 15 and Pl. II, *B*.) Operator, John L. Goss; office, Stonington, Me.

The granite is a biotite granite, identical with that of the Ryan-Parker quarry (specimen 20, *a*), described on page 102. The firm reports that a test of this stone made by the New York Dock Department showed a breaking weight of 18,000 pounds to the square inch.

The quarry, opened in about 1872, measures about 350 feet square; has a maximum depth of 120 feet and a minimum depth of 10 feet. Pumping is necessary in rainy weather. Little or no stripping has been required.

Rock structure: The sheets vary from 1 to 30 feet in thickness,

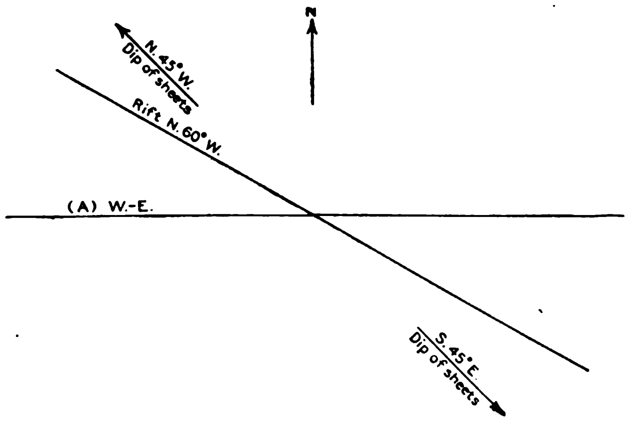

FIG. 17.—Structure at Goss quarry, Crotch Island.

increasing rapidly in thickness downward. They are horizontal in the center of the quarry, but south of it dip up to 20° SE. and north of it as steeply to the northwest. The joint courses and rift are shown in fig. 17. Of A there are only two or three in the quarry. Their faces are coated with epidote. There is no sap, but pyrite occurs in small particles rarely.

The plant consists of 8 derricks and 8 hoisting engines, 2 cable engines for drawing cars, 1 compressor (Ingersoll & Sargent, compound), with a capacity of 350 cubic feet of air per minute, 5 steam drills, 16 pneumatic hand tools, and 2 pumps.

Transportation is effected by means of three tracks—one 100, one 400, and one 500 feet long—from the quarry to the dock, the cars being propelled by cable engines.

The product is used chiefly for bridges and buildings. The small beds are worked into paving blocks. New York is the chief market. Specimen buildings of granite from this quarry are the post-office in Lowell, Mass.; the court-house at Dedham, Mass.; the Cadet armory at Boston; the public library at Laconia, N. H., and the Ninth Regi-

ment armory in New York. In 1905 this quarry was supplying the rough stone for the Brooklyn approach to East River Bridge, No. 3, New York, and the cut stone for the Manhattan approach to the same bridge, the trimmings for the University Heights Bridge, New York, and the stone for the Flushing, Long Island, Bridge.

The Sherwood quarries are north of Mill Cove, Crotch Island. Operators, S. Clinton Sherwood Company, No. 1 Madison avenue, New York. (See fig. 15 for location of quarries.)

The granite of the lower and northern quarry (specimen 25, *a*) is a biotite-muscovite granite of light-gray shade, with a very slight yellowish tinge, and of very fine texture, most of its particles ranging in size from 0.11 to 1.1 mm., the average diameter being about 0.45 mm. There are, however, occasional quartz particles and feldspar crystals one-fourth inch across, and of the latter rarely one a half inch in length, so that the rock has a porphyritic texture. The constituents, arranged in descending order of abundance, are potash feld-

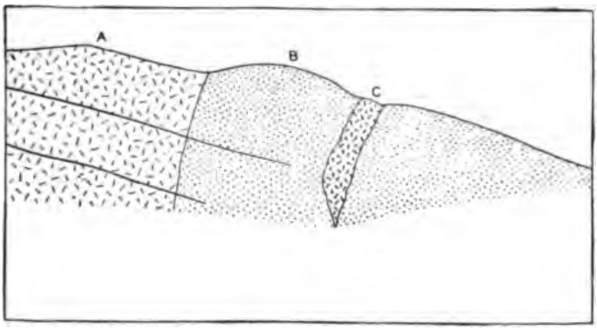

FIG. 18.—Relations of fine biotite-muscovite granite (B) to coarse biotite granite (A and C), and of sheet structure to both at north end of Sherwood quarry, Crotch Island. Length, 9 feet.

spar (microcline and orthoclase), smoky quartz, soda-lime feldspar (oligoclase), black mica (biotite), and white mica (muscovite), together with accessory magnetite and secondary epidote. The oligoclase is largely altered to a white mica and kaolin, and all the feldspars are in places intergrown with quartz circular in cross section.

The lower quarry, opened in 1889, is triangular in area, each side being 75 feet long and 40 feet deep, two of which are working faces. The drainage supplies the boilers.

Rock structure: The sheets, which are from 2 to 8 feet thick, dip 5° to 10° W. Joints, dipping 70° S. to 90° and striking N. 75° E., recur at intervals of 1 to 10 feet. The rift is vertical, with a course W. 60° N., as at the quarries south of the cove. The relations of this fine granite at the north end of the quarry to the coarse granite of the island are shown in fig. 18. The fine granite probably represents a later eruption through the coarser. (See p. 46.)

The plant consists of 1 derrick and 1 hoisting engine.

Transportation is had by track to wharf, 100 feet distant.

This quarry was idle in 1905 and is worked only on special orders.

The product is used for monuments, bases, etc., and finds its way usually to New London, Conn. The minor sheets and remnants are worked up into paving blocks.

The granite of the same firm's upper quarry, opened in 1890 (specimen 26, *b*), is a biotite granite of general pinkish buff-gray color and coarse even-grained texture, consisting of pinkish-buff potash feldspar, smoky quartz, cream-colored soda-lime feldspar and black mica. The potash feldspar measures up to an inch or more in length, and the biotite scales one-tenth inch. This stone appears to be identical with that of the Latty quarry on Green Isle (specimen 28, *a*).

The upper quarry is 200 by 100 feet, and averages about 15 feet in depth. The quarry drainage supplies the boiler.

Rock structure: The sheets are from 1 to 5 feet thick, and dip 5° to 10° E. and W. Vertical joints strike N. 50°–60° W. and parallel to the rift. For a space of 50 feet across the middle of the quarry these recur at intervals of from 2 to 8 feet. Another set, less numerous, strikes N. 25° W. and dip 60° E. There is an irregular tapering dike of pegmatite, with pink and white feldspar, biotite, and muscovite. The sheets in upper part of quarry have "shakes" for 2 to 3 inches from their surface.

The plant consists of 1 derrick and 2 steam drills.

Transportation is effected by cable and engine along a track 900 feet long to a dock on east side of the island.

The product consists of random stone and goes to New London, Conn.

The Latty Brothers quarry is in the southeast part of Green Island, which lies 1 mile southeast of Stonington. (See map, fig. 15.) Operators, Latty Brothers, Stonington, Me.

The granite (specimen 28, *a*) is a biotite granite of pinkish-buff color and coarse, even-grained texture, consisting of a pinkish-buff potash feldspar, smoky quartz, cream-colored soda-lime feldspar, and black mica. The potash feldspar measures up to an inch, and the biotite up to 0.15 inch in diameter. The stone appears to be identical with that of the upper quarry of S. Clinton Sherwood Company, on Crotch Island.

Rock structure: The sheets are from 6 feet to 6 feet 8 inches thick and dip gently southeast. There are vertical joints striking N. 45° W., spaced 6 to 12 feet, also forming a heading. The rift is vertical, with course N. 60° W.

The quarry was opened in the spring of 1905. The plant consists of 3 derricks, 2 engines, and 1 steam drill.

Transportation is effected along a track 100 feet long to wharf.

The product is random stone for bridges and buildings and goes to New York and Boston.

The Stonington granite quarry is on the west shore of Spruce Island, 3¼ miles east-southeast of Stonington. (See map, fig. 15.) Operator, E. L. Waite, Stonington.

The granite (specimen 27, *a*) is a biotite granite of pinkish buff gray color and very coarse semiporphyritic texture. It consists of a pinkish-buff potash feldspar in crystals measuring up to 1¼ inches in diameter, smoky quartz, cream-colored soda-lime feldspar (oligoclase) in particles and crystals up to one-half inch in diameter, and black mica in scales measuring up to 0.15 inch across. The contrasts between the two feldspars and the mica are strong. The smoky quartz is a little darker than the potash feldspar. Some of the pinkish-buff feldspar is rimmed with the cream-colored one.

Rock structure: The sheets, 5 to 8 feet thick, dip about 40° W. Vertical joints strike N. 45° E., N. 45° W., and N. 80° E.

The plant consists of 3 derricks and 2 engines.

The quarry was being opened in July, 1905.

The Moose Island quarry is in the southeast part of Moose Island, three-fourths mile west-southwest of Stonington. (See map, fig. 15.) Operator, John L. Goss, Stonington.

The granite is a biotite granite identical with that of the Goss and Ryan-Parker quarries on Crotch Island (specimen 20, *a*), for descriptions of which see page 102.

The quarry, opened in 1873, measures 600 by 200 feet and averages about 17 feet in depth. One corner of it is 4 feet below low-tide level, so that sea water enters, which, to the amount of 300 to 400 gallons, has to be pumped out daily.

Rock structure: The sheets, from 1 to 7 feet thick, dip from 5° to 10° E. Vertical joints striking N. 80° to 85° W. recur at intervals of 200 feet and form a heading on north side of quarry. There is no perceptible rift, and the rock does not split well when frozen. The 15-inch aplite vein, described on page 43, has a course N. 80° W. Sap, from 1 to 2 inches thick, is confined to the upper sheets.

The plant consists of 4 derricks and 4 engines, 2 locomotive cranes of 10 and 20 tons capacity, 1 compressor of 800 cubic feet capacity per minute, 2 steam or pneumatic drills, 8 pneumatic plug drills, 3 surfacers, 2 pneumatic hand tools, 1 steam pump, and 1 windmill pump.

Transportation is effected by cars on track 200 feet to wharf.

The product is used for bridges and buildings, and goes chiefly to New York.

Specimen structures: The gate house at Central Park and the steps of Columbia University, in New York; trimmings of the Hampton Dormitory at Cambridge, Mass.

Contracts in 1905: University Heights Bridge and part of the stone for No. 3 anchorage for Manhattan Bridge, New York.

The Settlement quarry is on Deer Isle, on Settlement Hill east of Webb Cove, 2 miles northeast of Stonington. (See map, fig. 15.) Operator, John C. Rodgers, 1909 Amsterdam avenue, New York.

The granite (specimen 22, *a*) is a biotite granite of medium gray slightly lavender tint, blotched with white, and of coarse texture, consisting, in descending order of abundance, of a very light lavender-colored potash feldspar (microcline and orthoclase), smoky quartz, slightly cream-colored soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite, titanite and apatite, and secondary chlorite. The potash feldspar is sometimes rimmed with oligoclase. The feldspars measure up to 1 inch and the biotite plates are under one-tenth inch. The contrast between the two feldspars and the mica is strong, but that between the quartz and the potash feldspar is feeble.

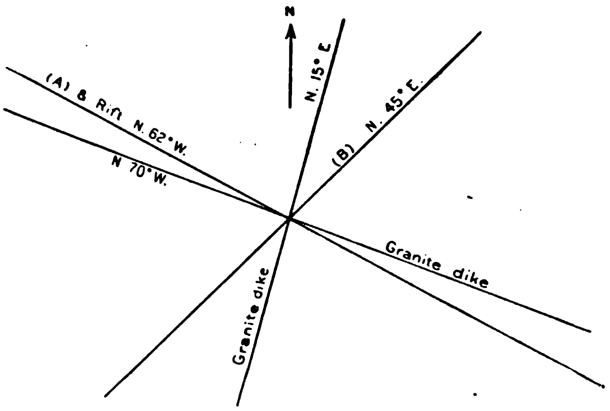

FIG. 19.—Structure at Settlement quarry, on Deer Isle, near Stonington.

The following test of the crushing strength of this stone was made by the Pittsburg Testing Laboratory (Limited) and is given here merely for reference:

Test of crushing strength on 3-inch cubes of granite from Deer Isle.

	Load applied.	Crushing strength per square inch.
	Pounds.	*Pounds.*
Specimen 1	151,000	16,610
Specimen 2	200,600	22,830
Specimen 3	151,300	17,220

Laboratory No. 17858, April 7, 1903; signed, John M. Bailey, Secretary.

Mr. Oren, United States inspector of building stone for Government contracts, stationed at Stonington in 1905, stated to the writer that he had tested this granite by immersing it in commercial hydrochloric acid for over three months without any bad effects.

The quarry, opened in 1900, consists of two openings, one near the top of the hill, 500 by 400 feet and from 10 to 18 feet in depth, the other on its west side, 600 by 60 feet and up to 14 feet in depth. Drainage requires occasional pumping. There is little or no stripping.

Rock structure: The sheets, from 6 inches to 16 feet thick, dip 10° to 15° north and south away from the top of the hill. Joint courses are shown in fig. 19. A occurs but once; B recurs at intervals of 500 feet. The rift is vertical with a course of N. 60°–65° W. There are granite dikes from 4 to 12 inches thick. (See description on p. 46.) Knots are rare and small. Pyrite occurs but very rarely.

The plant consists of 9 derricks and 3 engines, 1 traveling crane of 10 tons' capacity, 1 locomotive, 2 compressors each of 750 cubic feet capacity, 16 steam or pneumatic drills, 9 surfacers, 19 pneumatic plug drills, 8 pneumatic hand tools, and 2 steam pumps.

Transportation is effected by locomotive and 2,500 feet of track. The distance from upper quarry to cutting shed is 1,000 feet, and from cutting shed to wharf 600 feet.

The product is used for massive structures in New York and Norfolk, Va. The small sheets and waste are used in paving. Specimen structures: The approach to Williamsburg Bridge and the piers to Manhattan Bridge, New York. Contracts in 1905: Retaining wall for Riverside Drive, New York, and the dry dock in Norfolk, Va.

Hagan and Wilcox quarry is on Deer Isle, in Stonington village. Operators, Hagan and Wilcox, Stonington.

The granite is a coarse-textured, even-grained biotite granite like that of Green Island.

The quarry has two nearly adjacent openings, one 75 by 75 feet, the other 50 by 50 feet, and from 25 to 50 feet deep. Drainage is effected by occasional pumping.

Rock structure: The sheets, from 2 to 20 feet thick, are horizontal. Vertical joints, striking N. 80° E., recur at intervals of from 2 to 40 feet and also N. 20° W., recurring at intervals of from 10 to 20 feet. The rift is vertical, with course N. 30°–35° W. From the small spacing of its joints, this is technically a "bowlder quarry."

The plant consists of 3 derricks and 3 hoisting engines, 2 steam drills, and 1 pump.

Transportation is effected by cartage 1,000 feet to wharf.

The product is random stone, which is shipped to Philadelphia and cut there. Structure: A lace mill in Philadelphia.

The Calvin Ames quarry is on Deer Isle, 1 mile east of Stonington. Operator, Calvin Ames, Stonington.

The granite is a coarse-textured, even-grained biotite granite like that of Green Island (p. 106).

The quarry measures 75 feet square by 12 feet in depth.

Rock structure: The sheets, which are from 1 to 5 feet thick, are horizontal but irregular. Vertical or steep joints strike N. 80° E., N. 60° W., and N. 30° W. There is a foot of sap and "shakes" at the top.

The plant consists of 2 hand derricks at quarry and 2 more at the wharf, which is connected with the quarry by a 400-foot track.

The product is random and cellar stone, and is shipped to Boston and New York.

The Crabtree & Havey quarry is in the town of Sullivan, three-fourths mile from Sullivan River. Operators, Crabtree & Havey, North Sullivan.

The granites of the Franklin and Sullivan quarries, with but one or two exceptions, are of the general character described under group 9 on page 74.

The granite of the Crabtree & Havey quarry (specimen 69, *b*) is a biotite granite of medium-gray shade and fine to medium even-grained texture, consisting, in descending order of abundance, of milk-white potash feldspar (microcline and orthoclase), smoky quartz, a milk-white soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite. The stone from the lower sheets is a trifle darker than that described above, which represents that of the upper ones. The difference lies in the feldspar.

The quarry, opened in 1865, measures 300 feet from north to south and 200 feet from east to west and ranges in depth from 10 to 50 feet. It is drained by occasional pumping. The stripping consists of 2 to 3 feet of drift.

Rock structure: The sheets, from 3 to 8 feet in thickness, dip 10° W. and northwest. They are not very regular in the center of the quarry owing to their lenticular form, shown in Pl. V, *A* and *B*. Vertical joints strike N. 80°–85° W., forming a heading on the north, also N. 10°–20° E., bounding the quarry on the east. A diabase dike 5 feet wide occurs on the west side, faulted in two places with a displacement showing a thrust from the east. The rock contains many knots, some of them as large as 6 inches and a few 3 feet in diameter. Sap occurs along the sheets, but not invariably.

The plant consists of 3 derricks, 1 hoisting engine, and 1 pump.

Transportation is effected by cartage three-fourths mile to wharf.

The product is used for building, curbing, and crossings in Boston, Providence, and New York. The small beds go into paving blocks. A private residence in Chicago has been constructed of the granite. Contracts in 1905 were for random stone, curbing, and paving in Boston, New York, and Philadelphia.

The Hopewell quarry is in the town of Sullivan, on Sullivan River above the "falls." Operator, Hopewell Stone Company, 36 Main street, Bangor, Me.

The granite (specimen 68, *a*) is a biotite granite, of light to medium-gray shade and fine to medium even-grained texture, consisting, in descending order of abundance, of milk-white potash feldspar (microcline and orthoclase), smoky quartz, translucent white soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite. Many slender oligoclase crystals, most of them unaltered, measure between one-tenth and one-fifth inch. The contrasts are not strong. The stone takes a good polish, and the contrast between polished and cut face is fair. The general shade of this granite is but a trifle darker than the so-called "white granite" of North Jay, described on page 80, but its mineral particles are coarser and its biotite is more conspicuous.

The quarry, opened about 1855, is triangular in area, each side being about 200 feet long; the depth of the working face on the east is 40 feet, and the depth at front 20 feet. There is no drainage problem. The stripping consists of 2 feet of drift besides 6 feet of "top" or poor stone.

Rock structure: The sheets, from 2 to 12 feet thick, dip southwest at a low angle. Vertical joints strike N. 25°–30° E., forming a heading on the north, and also N. 60° W., the last recurring at irregular intervals and more or less discontinuously. The rift is horizontal and the grain vertical, with course N. 60° W. There is very little sap. Knots are few and small.

The plant consists of three derricks and two engines.

Transportation is effected by gravity tracks and cable to wharf 500 feet off. Schooners of 13 feet draft can pass the falls at high tide during one-half hour.

The product is random blocks, curbing, and crossings for Philadelphia, Boston, and New Jersey. The thin sheets and waste go into paving blocks. Contract in 1905: Base course of manual training school building, corner Broad and Jackson streets, Philadelphia.

The Stimson quarries are in the town of Sullivan. Owner, Mrs. C. A. Stimson, Sullivan. Leased by Hopewell Stone Company, but not operated in 1905. Reported as sold since the writer's visit.

The granite (specimen 67, *a*) is a biotite granite of medium-gray shade and fine to medium even-grained texture, consisting, in descending order of abundance, of gray potash feldspar (orthoclase and microcline), smoky quartz, grayish soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite. The biotite plates measure up to 0.15 inch across. The general shade of this granite is darker than that of the Hopewell quarry. Contrasts are slight, owing to similarity in shade of quartz and feldspar.

The quarries consist of three openings, the main one of which is 200 feet square and from 15 to 30 feet deep.

Rock structure: The sheets, from 1 to 5 feet thick, are horizontal, with slight undulations. Vertical joints strike N. 65° W., forming headings on the north and south side, also north, and coated in places with pyrite. The rift is horizontal. A vertical dike of aplite 1 foot 7 inches thick has a N. 10°–15° W. course. The amount of sap is small. Dark-gray knots up to 2 inches and exceptionally 7 inches in diameter occur.

The product was carted to a wharf a half mile off and shipped to New York.

Hooper, Havey & Co.'s quarry is in North Sullivan. Office, North Sullivan.

The granite is a biotite granite of medium-gray shade and fine to medium even-grained texture, like that of the Crabtree & Havey quarry (specimen 69, *a*) described on page 110.

The quarry, opened in about 1894, measures 300 by 150 feet by 15–20 feet in depth. As the bottom of the quarry is about 15 feet below the general surface there is much inflow of water along the sheets, as well as direct collection of rain water. Its drainage requires considerable pumping. After being idle in winter it requires three weeks' steady pumping to reopen it.

Rock structure: The sheets, from 6 inches to 6 feet thick, are gently undulating and horizontal. Vertical joints strike N. 20–25° E., forming the west side of quarry, and also east-west, forming a heading on its north side. The rift is horizontal, and the grain vertical, east-west. The rock is evidently under a compressive east-west strain, as it tends to fracture in a north-south direction across the grain, without regard to knox holes. The knots are small.

The plant consists of 3 derricks (horse) and 1 steam pump.

Transportation is by cartage of one-half mile to wharf.

The product is random stone and street material, mostly for Boston. Contracts in 1905: Curbing (straight and circular), crossings, and paving blocks for Philadelphia.

The Whalesback quarry, in North Sullivan, is operated by W. T. Havey, jr., & Son, of Franklin.

The granite is a biotite granite of medium-gray shade and fine to medium texture, like that of the Crabtree and Havey quarry described on page 110.

The quarry, opened in about 1868, is 200 feet square and from 8 to 30 feet deep. It is drained by a 2½-inch siphon pipe, 250 feet long. The stripping consists of 3 to 8 feet of drift. On one side the glaciated granite surface has a 2½-foot bowlder, excavated from the overlying drift, resting on it.

Rock structure: The sheets, from 2 to 8 feet thick, dip 5° to 10° SE. Vertical joints strike N. 85° E., forming headings at the north and south sides; also N. 10° E., parallel with a 4-inch diabase dike. A microscopic description of this dike will be found on page 48. The rift is horizontal and the grain vertical with east-west course. Knots are rare.

The plant consists of 2 derricks and siphon pipe.

Transportation is effected by cartage three-fourths mile to wharf.

The product is used for curbing and random stone in Philadelphia, New York, and Boston.

The Dunbar Brothers' quarry (leased from Crabtree and Havey) is 2½ miles northwest of Sullivan village, in the town of Sullivan. Address, Sullivan.

The granite is a biotite granite of medium-gray shade and coarse (inclining to medium), even-grained texture, like that of the Robertson & Havey quarry, in Franklin, described on page 90.

The quarry, opened in 1901, measures 250 by 100 feet and is from 4 to 8 feet in depth. Its drainage requires occasional pumping. The stripping consists of 2 feet of drift, with small bowlders.

Rock structure: Sheets, from 2 to 12 feet thick, undulate with a general easterly dip of 10°. Vertical joints strike N. 80°-85° E., forming a heading on south side of quarry, and N. 60° E. with a heading; also exceptionally N. 5°-10° E. The rift is horizontal. A diabase dike from 8 to 16 inches thick has a course N. 20°-25° E., and rims of epidote, as described on page 48. There is little or no sap, and knots are few.

The plant consists of 2 derricks (horse) and 1 pump.

Transportation is effected by cartage 1¼ miles to wharf.

The product is random, curbing, and paving, which go to Boston, New York, and Philadelphia.

The Harvey Dunbar quarries consist of several small openings in West Sullivan, operated by Harvey Dunbar (address, Sullivan), who employs 8 men in getting out paving blocks.

The Taylor quarry is in the town of Sullivan, on the west side of a north-south ridge, 2 miles from Sullivan village. Owner, Harry Taylor, North Sullivan. Quarry not operated in 1905.

The granite (specimen 79, *a*) is a biotite granite of medium-gray shade and fine to medium even-grained texture, consisting, in descending order of abundance, of grayish potash feldspar (orthoclase and microcline), smoky quartz, grayish soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite. The feldspars measure from 0.1 to 0.25 inch and the biotite scales up to 0.1 inch. The rock is identical with that of the Stimson quarry, described on page 111.

The quarry, opened recently, measures 50 by 25 feet and 5 feet in depth. The sheets, from 2 to 5 feet thick, dip 20°–30° W. Vertical joints strike N. 25°–30° E. There is one derrick.

The Pettee black-granite quarry is three-fourths mile north of East Sullivan, on the road to Tunk Pond. Owner, J. A. Pettee, East Sullivan.

This rock (specimen 80, *b*) is a mica-quartz diorite of very dark gray shade and fine to medium texture with occasional porphyritic whitish feldspars up to one-fourth and more rarely one-half inch. It consists, in descending order of abundance, of white translucent soda-lime feldspar (oligoclase-andesine), black hornblende, opalescent quartz, black mica (biotite), and magnetite, together with accessory titanite, apatite, and pyrite. It takes a fine polish, and the contrast between polished and cut surfaces is marked. The diorite of East Sullivan is referred to by W. O. Crosby in a paper on the Geology of Frenchmans Bay.[a]

The quarry, which is only 15 by 15 feet and 8 feet deep, is on the west side of a knoll 20 to 25 feet high.

Rock structure: Vertical joints striking N. 25° W. and N. 85° W. recur at intervals of 1 to 5 feet. The rock splits in these directions also horizontally. There are whitish bands or veins one-half inch thick, consisting almost entirely of the feldspar and quartz.

This stone is quarried occasionally in small blocks for monumental purposes.

The Sinclair black-granite prospect is 1½ miles north of East Sullivan, on Herbert and Thaddeus Sinclair's (formerly Smith Bean's) farm, near Charles Dowel's sawmill.

This rock (specimen 82, *a*) is a quartz monzonite of almost black shade, with white blotches, of medium to coarse (porphyritic) texture, consisting, in descending order of abundance, of bluish opalescent quartz, whitish soda-lime feldspar (oligoclase-andesine), and potash feldspar (microcline and orthoclase), black hornblende, and black mica (biotite), together with accessory magnetite, pyrite, titanite, and apatite. Some of the feldspars measure nearly an inch in length. This is closely related to the true granites, as it contains nearly as much potash feldspar as soda-lime feldspar, although it is among the darker of the "black granites."

The ledge is exposed for a length of 50 feet north-south and a height of 20 feet. A vertical joint strikes N. 20° W. An opening 10 by 5 feet and 5 feet deep was made here in 1902.

The Baird quarry is on Swans Island, east side of old harbor, not quite 1 mile east of Swans Island village and three-fourths mile southeast of Mintum. Operators, The Mathew Baird Contracting Company, 433 East Ninety-second street, New York.

[a] Proc. Boston Soc. Nat. Hist., vol. 21, 1880, p. 110.

The granite (specimen 34, *a*) is a biotite granite of medium pinkish-buff gray color and of medium, inclining to coarse, even-grained texture, consisting, in descending order of abundance, of a pinkish-buff potash feldspar (orthoclase and microcline), smoky quartz, a milk-white soda-lime feldspar (oligoclase) and black mica (biotite), together with accessory magnetite, and, rarely, a little greenish hornblende. The potash feldspars are intergrown with plagioclase and measure up to over one-half inch, but most of the biotite is considerably under one-tenth inch. The stone takes a good polish, but the contrast between the polished and rough surface is feeble, owing to the smallness of the biotite scales. The contrasts are mostly between the quartz and the feldspars. The company reports a test of crushing strength of between 18,000 and 19,000 pounds per square inch.

The quarry, opened in 1901, measures 500 by 250 feet and has an average depth of 15 to 18 feet. The drainage supplies the boilers. There is no stripping.

Rock structure: The sheets, from 1 to 7 feet thick, dip 15° south. Vertical joints, striking N. 45° E., recur at intervals of 50 feet; others, striking N. 80° W., recur but twice as continuous joints. The rift is vertical, north-south. Sap is confined to the sheets of the upper 3 feet. No knots or veins.

The plant consists of 3 derricks, 3 engines, a steam drill. and a steam pump.

Transportation is effected by gravity and cable on a track to wharf, 1,200 feet off.

The product is random, dimension, and paving stone, which go to New York, where the firm has its cutting works.

The Toothachers Cove quarry is near end of that cove, in the western part of Swans Island, 1½ miles north-northwest of Swans Island village. The property is owned by B. E. Rowe, of Swans Island. The mineral right was leased to Wilbur and Havey, address, Swans Island, but is now held by C. J. Hall of the same place. In the fall of 1905 a company was being formed to operate the quarry.

The granite (specimen 33, *a*) is a biotite granite of medium pinkish-gray color and coarse, even-grained texture, with feldspars up to three-fourths inch and biotite fully one-tenth inch. It consists, in descending order of abundance, of light-pink potash feldspar (orthoclase), smoky quartz, cream-colored soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite and titanite. The orthoclase is intergrown with plagioclase. The oligoclase is altered to a white mica. The contrasts between the four minerals are marked.

The quarry is 50 by 25 feet, and the working face is 20 feet high. There are two other small openings.

Rock structure: The sheets are from 5 to 12 feet thick and horizontal. Vertical joints, striking N. 60° W., recur at intervals of 10 feet. There are veins of aplite and of quartz.

In July, 1905, the plant consisted of a horse windlass and derrick. An inclined track leads to the wharf, 400 feet off.

Product: Random and paving blocks.

The Seal Cove quarries are in the town of Tremont, on Mount Desert Island, about one-half mile southeast of Murphy Hill. Operator, S. W. Herrick, Southwest Harbor, Maine.

The granite (specimen 57, *a*, from lower opening, collected by writer) is a biotite granite of dark-gray shade and medium (inclining to fine) even-grained texture, with feldspar up to one-fourth inch and black mica generally under one-tenth inch. It consists, in descending order of abundance, of bluish-gray soda-lime feldspar (oligoclase) and a little black mica (biotite), together with accessory magnetite. The difference in the amount of the two feldspars appears to be less than in specimen 57, *c*, and this granite thus approaches a quartz monzonite. There is little contrast between the quartz and feldspars, and the biotite plates are small and thinly disseminated. The granite (specimen 57, *c*, probably from the upper quarry, collected by the operator) is like specimen *a*, except that its color is dark greenish, in consequence of the feldspars being greenish gray, and that the two feldspars occur in their usual proportions. It contains some secondary epidote and takes a fair polish.

The quarries, opened in 1903, consist of several small openings, none of which exceed 25 feet square.

Rock structure: The sheets, from 1 to 3 feet thick, are horizontal at the upper quarry, but dip 10° to 25° W. at the lower one. Vertical joints strike 10° to 15° W. and also N. 90° W. The rift is horizontal. Sap from 2 to 3 inches thick occurs along the sheets. Dark-gray knots, up to 2 inches across, occur occasionally.

The product, paving blocks thus far, is carted three-fourths mile to wharf in Seal Cove.

The Carroll quarry is in the town of Tremont, on Mount Desert Island, at Southwest Harbor. Owned by estate of Jacob W. Carroll. Address, John Carroll, Southwest Harbor.

The granite (specimen 65, *a*) is a hornblende granite, of pinkish-greenish medium-gray color and medium even-grained texture, consisting, in descending order of abundance, of pinkish-greenish potash feldspar (microcline), smoky quartz, very dark green hornblende, and very little black mica (biotite), together with accessory magnetite and zircon and secondary chlorite. The microcline is intergrown with quartz and soda-lime feldspar (oligoclase-andesine), and is largely altered to kaolin and a white mica. This granite is like that

of the Graves quarry (specimen 64, *a*), page 100, except that the feldspars are more pinkish.

The quarry is 100 feet from north to south by 30 feet from east to west, and has a working face on the east 15 feet high. The sheets, from 6 inches to 3 feet thick, are horizontal at the north end, but dip 10° S. at south end. Vertical joints strike N. 75° E. and N.50°–55° W. Knots are abundant and are up to 2 feet in diameter.

The quarry is only worked occasionally, and the stone is used locally for foundations.

The Orland quarries, situated in the vicinity of Orland, in Hancock County, were reported as not in operation in 1905 and were not visited.

KENNEBEC COUNTY.

The quarries in Kennebec County are in the town of Hallowell.

The Stinchfield and Longfellow quarries are in the town of Hallowell, 2½ miles northwest of the city of Hallowell, on the southern part of Lithgow Hill. (See map, Pl. I.) Operator, Hallowell Granite Works, Hallowell.

The granite (specimen 111, *a*) is a biotite-muscovite granite of light-gray shade and fine texture, with porphyritic feldspars usually about one-fourth inch in diameter. It consists, in descending order of abundance, of slightly bluish translucent potash-feldspar (orthoclase and microcline), smoky (light) quartz, soda-lime feldspar of same colors as the other (oligoclase), black mica (biotite), and white mica (muscovite), together with accessory garnet, zircon, and apatite. The oligoclase is usually undergoing alteration to kaolin and a white mica and contains intergrowths of quartz circular in cross section. Leaving the porphyritic feldspars out of consideration, the general diameter of the particles ranges from 0.25 to 1.0 mm., averaging about 0.65. The micas are thickly disseminated. The stone takes a fine polish, and the polished face has a slight bluish tinge. A microscopic description of Hallowell granite will be found in Merrill's Stones for Building and Decoration, pages 63, 64.

Mr. E. C. Sullivan, as a result of tests at the chemical laboratory of the United States Geological Survey in May, 1906, found that this granite contains 0.060 per cent of CO_2 (carbon dioxide) and that warm dilute acetic acid dissolves 0.08 per cent of CaO (lime) and a trace of MgO (magnesia). If all of this CO_2 is assigned to the CaO, the rock contains 0.14 per cent of $CaCO_3$ (lime carbonate). The lime extracted by this process is in addition to that combined with silica in the soda-lime feldspar. The thin sections from the Tayntor quarry stone, which is essentially the same, show a little carbonate (see p. 120), and the same mineral must occur also in the

stone from the Stinchfield and Longfellow quarries, but in very minute quantity.

A test of the crushing strength of this granite made by Ricketts and Banks yielded the following results:

	Pounds per square inch.
First cube	19,260
Second cube	15,730
Average	17,495

The difference in the two cubes is attributed to some imperfection in the second one.

The quarries were opened about 1826. The Stinchfield quarry measures 600 feet from northeast to southwest by 400 across and from 30 to 60 in depth. (See Pl. IV, *B*.) The Longfellow quarry (not in operation, but filled up to 20 feet with water), southwest of

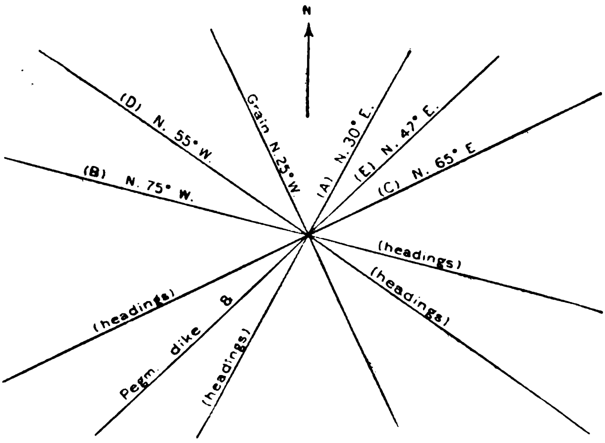

FIG. 20.—Structure at Stinchfield and Longfellow quarries, near Hallowell.

the above and communicating with it, measures about 400 by 200 feet and from 50 to 70 feet in depth. The drainage of the Stinchfield quarry requires pumping for a few hours after heavy rains, and that drainage supplies the boilers. The stripping consists of from 1 to 20 feet (increasing northwestward) of yellowish sandy clay with small bowlders near the top. (See Pl. IV, *B*.)

Rock structure: The most striking features in these quarries are the gradual increase in the thickness of the sheets downward (partly shown in Pl. IV, *B*), which ranges from 4 inches to 14 feet, and the evidence of strain afforded by the numerous headings and joint systems shown in fig. 20; also the evidence of weathering afforded by the decomposition and discoloration along these headings. The sheets range from a horizontal position to an inclined one of 15° *NE.* Many of them stop at the joints, probably owing to faulting;

some taper out and overlap. Pl. IX, *B*, a view of a part of the northwest wall of the Longfellow quarry, shows the intersection of headings of joint systems C and D. Joints A are spaced from 10 to 50 feet. B forms a heading 50 feet wide on the southeast wall, weathered yellow to a depth of 50 feet from the rock surface. Joints C are spaced from 5 to 70 feet. In a 2-foot heading of C on the southwest wall the joints recur at intervals of 2 inches to one-half inch and are coated with quartz crystals. Joints D form two headings, 10 feet wide, on the southeast wall, containing a bed of sand a foot thick and 30 feet deep or long. Joints E are discontinuous and grooved and polished from motion. Large areas of some of the joint planes in the Longfellow quarry are covered with frost-like crystallizations of oxides of iron and probably of manganese. The rift is horizontal; the grain is vertical N. 25° W., but feeble. A 2-foot pegmatite dike contains milk-white oligoclase, smoky quartz, muscovite, biotite, and 1-inch garnets. Knots occur up to three-fourths inch across, exceptionally 1 by 3 inches. The sap is very marked along the joints and up to a foot in thickness. The concentric growth of ferruginous discoloration is shown in the heading Pl. IX, *B*.

The plant (including both that at the quarries and at the Hallowell cutting sheds) consists of 18 derricks, of which 3 are worked by electricity, 3 by hand, and the rest by 6 engines; 2 traveling cranes, of 10 and 20 tons capacity; 2 compressors, of 180 and 900 cubic feet per minute capacity; 14 pneumatic plug drills; 2 1-foot plug drills; 5 surfacers; 3 polishers; 56 pneumatic hand tools; 1 lathe for stone 16 by 2 feet, 2 for stone up to 6 by 2 feet; 2 polishing lathes for stone 16 by 2 feet, and 3 steam pumps.

Transportation is effected by cartage 2½ miles to railroad or to wharf on the Kennebec River at Hallowell, accessible to schooners of 12-foot draft.

The product is used for buildings and sculpture. It lends itself remarkably well to statuary and delicate ornamental work, as is shown by Pl. XIV, *A*, a reproduction of a photograph of a panel at the entrance to the Bank of Commerce in New York, and by Pl. XIV, *B*, representing a statue recently finished for the Hall of Records in the same city. About seven-eighths of the product go into building and one-eighth into carved work. The principal markets are Chicago and New York. Specimen buildings: Albany capitol, Hall of Records (including its statuary), New York; Brooklyn Savings Bank, New York; Masonic Temple, Boston; academic and library buildings at United States Naval Academy, Annapolis, Md.; Illinois Trust Company's building, Chicago; Northwestern Insurance Company's building, Milwaukee; post-office at Allegheny,

Pa. Specimen monuments and statues: Statuary on Plymouth monument, Massachusets; National monument at Yorktown, Va.; New York State monument at Gettysburg, Pa.; Soldiers' monument at New Haven, Conn.; Richard M. Hunt monument in Central Park, New York; Battlefield monument at Trenton, N. J. Contracts in 1905: Suffolk Savings' Bank building, Boston; several mausoleums for New Orleans, Pittsburg, and Chicago; ex-Governor Cleaves's monument at Portland, Me.

The Tayntor quarry (formerly known as the Melvin quarry) is in the town of Hallowell, 2 miles north-northwest of the city of Hallowell. Operator, C. E. Tayntor & Co.; office, Hallowell (C. E. Tayntor, 239 Broadway, New York).

The granite is a biotite-muscovite granite of light-gray shade and fine (but porphyritic) texture, identical with that of the Longfellow and Stinchfield quarries (specimen 111, *a*) described on page 117. The general diameter of particles, excluding the porphyritic crystals, ranges from 0.25 to 1.25 mm. One of the small porphyritic oligoclase crystals measuring 2.25 mm. in diameter shows calcite between its cleavage planes. Calcite appears also independently in plates up to 0.5 mm. across. Mr. E. C. Sullivan, of the United States Geological Survey, tested granite from the Tayntor quarry and found that it contained 0.146 per cent of CO_2 (carbon dioxide) and that warm dilute acetic acid extracted 0.24 per cent of CaO (lime) and no magnesia. The CO_2 found corresponds to 0.33 per cent of $CaCO_3$ (lime carbonate). The difference in the result of the test of this and the test of the Stinchfield quarry stone may not hold good of the stones in general. The average of both tests or 0.235 per cent for the lime carbonate of both stones may be nearer the truth.

The quarry, opened before 1840, measures 520 feet N. 30° W. to S. 20° E., by 275 feet across and from 10 to 40 feet in depth. The deeper part of it is 275 by 150 and 40 feet deep. It is drained by pumping after rain. In places the glaciated granite surface is covered with 5 feet of sand and bowlders.

Rock structure: In places there is a vertical flow structure with course N. 35° W., and where it occurs it is the direction of easiest fracture. The sheets measure from 1 foot to 6 feet 6 inches (the thicker being the lower ones), and are horizontal. The joint and dike courses are shown in fig. 21. A recurs at intervals of 20 to 200 feet, and forms one heading, which does not extend beyond a depth of 15 feet from the rock surface. B sometimes dips steep north, recurs at intervals of 10 to 40 feet and forms headings in the northern half of quarry. The rift is horizontal and grain vertical, N. 70° W., but feeble. Fig. 21 shows the courses of the pegmatite dikes. *a* dips 45° N. and is 4 inches thick, *b* dips 65° E. and is 3 inches thick, *c* dips N. and is 3 inches thick. Pegmatite lenses 2 feet thick also

occur. In the north part of quarry there is a band of dark knots, from 5 to 25 feet wide, with a N. 10° E. course, but the rest of the quarry is free from knots. The glaciated surfaces and the sheet surfaces are free from sap except near the headings, where it extends for 6 inches from each sheet and joint face. The granite is here under compressive strain, for the cores between the contiguous borings made in channeling become crushed, and on two occasions spontaneous vertical east-west fractures 40 feet long occurred through a sheet 4 feet 6 inches thick, and diagonal to two rectangular "channels."

The plant consists of 3 derricks, operated by 1 engine (Ledgerwood hoist, triple drum); 1 compressor (capacity 180 cubic feet of air per minute), driven by a 30-horsepower Westinghouse electric motor; 4

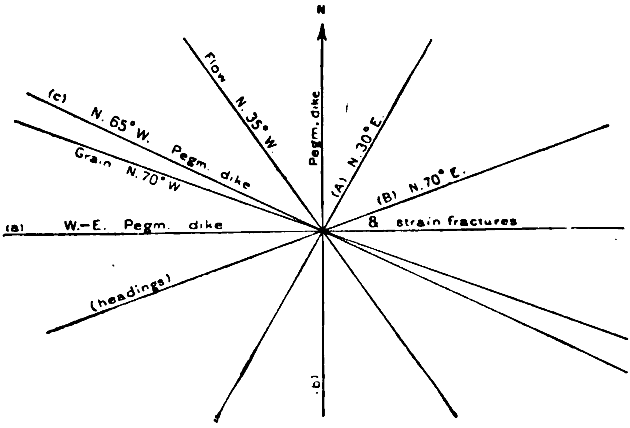

FIG. 21.—Structure at Tayntor (Melvin) quarry, near Hallowell.

steam drills; 1 pneumatic plug drill; 1 surfacer; 1 polisher; 9 pneumatic hand tools, and 2 steam pumps. New machinery is to be put into the new building, which is in process of construction.

Transportation is by cartage, 1¾ miles to the cutting shed and one-fourth mile farther to wharf or railroad. The company's new works will have a dock at one end and railroad at the other.

The product is used for monumental work. Specimen monuments: The General Slocum monument at Gettysburg, Pa.; the State of Maine monument at Andersonville, Va.; the New York State monument at Lookout Mountain (Craven House), Tennessee; the soldiers' monument at Pittsfield, Me.; the Dunlap mausoleum (Corinthian style, 16 by 28 feet); and the Ziegler mausoleum (Grecian Doric style, 25 by 34 feet, after the temple at Paestum), both at Woodlawn Cemetery, New York. Contracts in 1905: The General Miles mausoleum at Arlington, Va., and the Latham mausoleum at Hopkinsville, Ky.

About 100,000 paving blocks are made annually from waste and thin sheets.

KNOX COUNTY.

The quarries in Knox County are in Muscle Ridge Plantation and the towns of St. George, South Thomaston, Tenants Harbor, and Vinalhaven.

The High Isle quarry is in Muscle Ridge Plantation, 9½ miles south-southeast of Rockland. Operator, William Gray & Son; office, Thirtieth street, below Walnut, Philadelphia, Pa.

The granite (specimen 18, *a*) is a biotite granite of slightly pinkish medium-gray color, with conspicuous black mica and of medium to coarse, even-grained texture, the feldspars measuring up to one-half inch and most of the biotite scales up to one-tenth inch, but some one-fifth inch. It consists, in descending order of abundance, of a delicate pink potash feldspar (orthoclase and microcline), smoky quartz, milk-white (very slightly bluish) soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite, apatite, and secondary chlorite. The oligoclase is in some places partially altered to a white mica. The contrasts between the minerals are rather marked, but the polish is not very satisfactory, owing to the large size of the biotite scales.

The following chemical analysis and determination of specific gravity were made for the firm by Prof. James F. Kemp, E. M., of Columbia University:

Analysis of granite from quarry at High Isle quarry.

SiO_2 (silica)	74.54
Al_2O_3 (alumina)	13.30
FeO (ferrous oxide)	0.79
Fe_2O_3 (ferric oxide)	0.92
CaO (lime)	1.26
MgO (magnesia)	0.009
Mn (manganese)	0.51
S (sulphur)	0.038
Na_2O (soda)	3.69
K_2O (potash)	5.01
	100.067

Loss on ignition, 0.55.

Specific gravity, 2.641, equal to 165.06 pounds per cubic foot.

The results of four crushing tests on cubes (2-inch) bedded with plaster of Paris, made at the engineering laboratory of Columbia University for the firm, are as follows: First crack at 100,000 to 126,300 pounds. Ultimate strength in pounds per square inch, 25,880, 32,360, 32,495, 33,085. (Laboratory Nos. 1759 to 1761.)

The quarry, opened about 1894, consists of five openings, each about 100 feet square, with a maximum depth of 50 feet and an average

depth of about 17 feet. The drainage requires pumping. The stripping is insignificant, but in places is from 5 to 10 feet thick.

Rock structure: The sheets, which are from 2 to 14 feet thick, are lenticular, tapering, and curve over to the northwest and southeast at low angles. (See Pl. VIII, *A*.) Joint courses are shown in fig. 22. System A is prominent and forms a heading on the south side of the island, shown in Pl. VIII, *A*. B dips 40° SE., occurs but occasionally, and is discontinuous. C also forms a heading. D dips 65° SW. and is also prominent. The rift is vertical, with east-west course. Irregular horizontal dikes of pegmatite, up to 2 inches thick, consist of the same minerals as the granite—a pink orthoclase and microcline, smoky quartz, cream-colored oligoclase, and biotite. Sap occurs along the sheets and joints A and C, and markedly at the surface in places up to a foot in thickness. (For details see p. 53 and

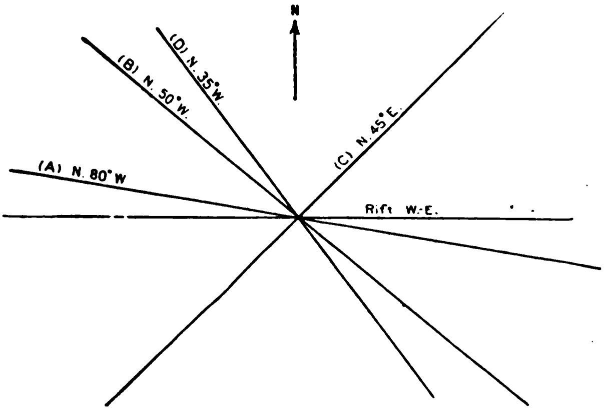

FIG. 22.—Structure at High Isle quarry, Knox County.

fig. 2.) Along some of the headings of A the granite is weathered to a sand at a depth of 20 feet.

The plant consists of 9 derricks, worked by 8 engines; 2 locomotive cranes, 2 compressors (with a capacity of 862 cubic feet per minute), 15 large pneumatic drills, 28 pneumatic plug drills, 13 surfacers, and 20 pneumatic hand tools.

Transportation is effected by gravity and track 650 feet to wharf.

The product is used for buildings, chiefly in Philadelphia. Sundry small buildings and bridge seats for the Pennsylvania Railroad have been made of this stone. Contract in 1905: The new Wanamaker store in Philadelphia.

Dix Island quarries, Muscle Ridge Plantation, one-half mile southwest of High Isle. Owner, Thomas Dwyer, 1613 Amsterdam avenue, New York.

Six openings were operated extensively in 1880 by the Dix Island

Granite Company, which employed 1,400 men when filling large contracts. These quarries furnished material for the United States Treasury Department extension at Washington, the basement of the Charleston custom-house, the New York and Philadelphia post-offices, and the trimmings for the New York Metropolitan Museum of Art. Only an occasional block is now quarried. There is a wharf with 12 feet of water at low tide. These quarries are referred to by J. E. Wolff in Tenth Census, vol. 10, 1888, pp. 119, 120, and by G. P. Merrill in Ann. Rept. Smithsonian Inst., pt. 2, 1889, p. 416.

The granite (specimen 19, *a*) is a biotite granite of somewhat dark gray shade and of medium to coarse even-grained texture, with feldspars up to one-half inch and numerous fine biotite scales rarely exceeding one-tenth inch. It consists, in descending order of abundance, of delicate pink potash feldspar (orthoclase and microcline), smoky quartz, a very slightly bluish white soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite and apatite. The oligoclase is partly altered to a white mica and rarely contains a little calcite. The biotite is here and there interleaved with muscovite. The chief difference between this and the High Isle granite is that in this the biotite scales are generally smaller and much more abundant, which darkens the shade of the rock and diminishes the contrast between the minerals.

Rock structure: The sheets are from 2 to 10 feet thick and dip 20° to 40° S. in places. Headings strike N. 80° E. and N. 35° W.

The Sprucehead quarry is on Sprucehead Island, in the town of St. George, about 10 miles south of Rockland. Operator, Bodwell Granite Company, Rockland, Me.

The rock (specimen 10, *a*) is a quartz monzonite, with conspicuous black and white particles and medium to coarse even-grained texture, consisting, in descending order of abundance, of translucent white soda-lime feldspar (oligoclase), milk-white potash feldspar (microcline), smoky quartz, black mica (biotite), and black hornblende, together with accessory titanite, magnetite, pyrite, zircon, apatite, and secondary epidote. Zonal structure is common in the oligoclase. The contrasts between the black minerals, the smoky quartz, and the feldspars are very marked.

The quarry is about 275 feet by 250 feet and has a maximum depth of 55 feet and an average depth of about 27 feet. Those parts of the quarry that lie below sea level require pumping. No stripping is necessary.

Rock structure: The sheets, which range in thickness from less than a foot to 13 feet, lie horizontal or dip from 10° to 15° northwest and southwest, intersecting the surface, which dips gently southeast. The sheets are irregular in thickness, owing to the tapering out of the lenses, but in general increase in thickness downward. Joints

and dike courses are shown in fig. 23. A recurs frequently on the north side of the quarry, but two joints are 50 feet apart and have greatly facilitated the opening of the quarry. B dips 70° N., traversing the entire quarry. The rift is vertical with a N. 60° E. course. Knots and dikes occur. Sap is 3 inches thick on the sheet surfaces.

The plant consists of 4 derricks, operated by 4 engines; 1 compressor, with a capacity of 527 cubic feet of air per minute; 2 steam drills; 3 surfacers. Pneumatic drills and tools were about to be added.

Transportation is effected by cartage 300 feet to wharf.

The quarry was idle in July, 1905, but preparations were being made for resuming work.

The product, consisting chiefly of building stone and some random and paving blocks, finds a market mostly in the West and South. Specimen buildings, etc.: Carnegie Library at Alleghany, Pa.; the

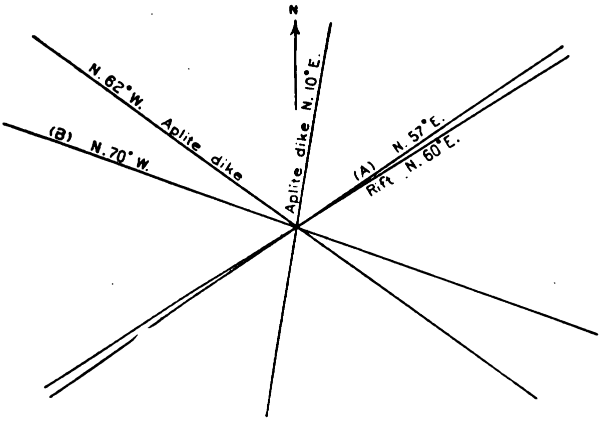

FIG. 23.—Structure at Sprucehead quarry, St. George.

new post-office and custom-house at Atlanta, Ga.; the columns of the Auditorium building, Chicago, Ill.; the Mutual Life Insurance Company's building, New York.

The Clark Island quarry is on Clark Island, in the town of St. George, about 12 miles south-southwest of Rockland. Operator, John C. Rodgers; office, 1909 Amsterdam avenue, New York.

The granite (specimen 12, *a*) is a biotite-muscovite granite of bluish, medium-gray color and of fine to medium even-grained texture, with feldspar up to one-fourth inch and mica under one-tenth inch. It consists, in descending order of abundance, of light-bluish potash feldspar (microcline and orthoclase), clear or very slightly smoky quartz, light-bluish soda-lime feldspar (oligoclase), black mica (biotite), and white mica (muscovite), together with accessory garnet, zircon, apatite, and secondary chlorite. The oligoclase is partly

altered to a white mica and includes a little carbonate. The quartz contains hairlike crystals of rutile (?). In general, as the quartz is so nearly clear, the bluish tint of the feldspar dominates and the contrast is mostly between it and the thickly disseminated black mica. It takes a very fine polish.

Mr. E. C. Sullivan, of the United States Geological Survey, finds that this granite contains 0.218 per cent of CO_2 (carbon dioxide), and that warm dilute acetic acid extracts 0.24 per cent of CaO (lime), and much MgO (magnesia). Figuring the CO_2 to both CaO and MgO, this would give 0.43 per cent of $CaCO_3$ (lime carbonate) and 0.06 per cent of $MgCO_3$ (magnesium carbonate). As stated above, the thin section also shows carbonate.

Two tests of the crushing strength of this stone, made by the Pittsburg Testing Laboratory (Limited) in March, 1899 (laboratory No. 13396, 13397), yielded 13,000 and 15,175 pounds per square inch, and are given here merely for reference.

The quarry, opened about 1870, is 500 by 300 feet, and has a maximum depth of 50 feet and an average depth of 25 feet. A very little pumping suffices for drainage. There is no stripping.

Rock structure: The sheets, from 2 to 10 feet thick, strike N. 30° W. and dip 20° E., and on the east side of the quarry 20°–30° W. They do not conform to the topography of the surface. Vertical joints strike N. 65°–70° W., recurring at intervals of 10 to 20 feet. The rift is vertical, with a N. 85° W. course. There are two dikes of coarse pegmatite, up to 6 inches thick, one striking N. 15° W., the other N. 40° E. They consist of feldspar, quartz, muscovite, biotite, black tourmaline, and red garnet. The usual sap occurs along the sheets.

The plant consists of 8 derricks and 8 hoisting engines, 1 overhead traveling electric crane of 16 tons capacity and 1 hand crane of 2 tons capacity; two compressors (capacity 850 and 300 cubic feet of air per minute), 4 steam drills, 7 pneumatic plug drills, 8 surfacers, 2 polishers (Jenny Lind), 2 small polishing lathes, 22 pneumatic hand tools, and 2 steam pumps, throwing 6-inch and 4-inch streams.

Transportation is effected by horse power on track 900–1,200 feet long, extending to wharf.

The product is used for building and ornamental work. Specimen buildings: The Hartford, Conn., and Buffalo, N. Y., post-offices; the Standard Oil building in New York. In 1905 the cutting plant was working on Stonington granite for the United States dry dock at Norfolk, Va.

The McConchie black-granite quarry, in the town of St. George, about three-fourths mile north of Long Cove quarry. Operator, George McConchie (Crown Granite Works); office, South Thomaston.

The rock (specimen 16, *a*) is a norite of very dark gray shade and fine to medium texture, consisting, in descending order of abundance, of an unaltered colorless to smoky feldspar containing both soda and lime (andesine to labradorite), hypersthene partly altered to brown hornblende, black mica (biotite) in scales up to 0.2 inch, and magnetite, together with accessory pyrite.

The quarry, opened in 1888, is about 50 feet square and from 10–15 feet deep and is provided with one derrick.

The stone has to be carried 10 miles to the cutting works at South Thomaston, although the quarry itself is within one-fourth mile of seaboard.

The product is used entirely for monuments. Specimen structures: The soldiers' monuments at Warren and Union, in Maine.

The Flat Ledge quarry, in the town of St. George, north of Clark Island, consists of several small openings (" motions ") operated by Edwin Edwards. Address, Clark Island.

The granite (specimen 13, *a*) is a biotite-muscovite granite of dark-gray color and fine, even-grained texture, with flow structure, consisting, in descending order of abundance, of a white potash feldspar (microcline and orthoclase), clear or barely smoky quartz, white soda-lime feldspar (oligoclase), black mica (biotite), and white mica (muscovite). But for its fine texture and less abundant muscovite this granite would belong in group 10, page 74.

The paving blocks are carted 1¼ miles to wharf.

The Weskeag quarry is in the town of South Thomaston, 1 mile west of Pleasant Beach, which is 7 miles south of Rockland. Operator, C. E. Hudson, South Thomaston.

The granite (specimen 142, *a*) is a biotite-muscovite granite of slightly bluish medium-gray color and of medium to coarse, even-grained texture, with feldspars up to one-half inch and mica 0.15 inch. It consists, in descending order of abundance, of light-bluish potash feldspar (orthoclase and microcline), smoky quartz, bluish or white soda-lime feldspar (oligoclase), black mica (biotite), and white mica (muscovite), together with accessory garnet, magnetite, and apatite. The oligoclase is partly altered to kaolin and a white mica. Thin sections show a marked rift, described on page 27 and shown in fig. 1 (p. 28). The stone takes a fine polish, but the abundance and size of the mica plates are not favorable to the durability of the polish under outdoor exposure.

The quarry, reopened in 1905, and still in process of development, covers about an acre of ground and has an average depth of 20 feet. The sheets are horizontal and tapering, lenticular. Joints strike N. 80° E. and dip 80° south. Rift is vertical and strikes N. 80° E. Grain is horizontal. (Quarry data collected by Mr. E. S. Bastin, of the United States Geological Survey.)

The plant consists of 2 derricks, 1 hoisting engine, 1 steam drill, and 1 steam pump.

Transportation is effected by cars and horsepower on a track one-half mile long to wharf near Birch Point.

The Long Cove quarry is in the town of Tenants Harbor, on Long Cove, St. George River, about 13 miles southwest of Rockland. Operator, Booth Brothers & Hurricane Isle Granite Company; offices, Rockland, Me., and 207 Broadway, New York.

The granite is a biotite-muscovite granite of bluish medium-gray color and of fine to medium even-grained texture like that of the Clark Island quarry, described on page 125. Tests of its compressive

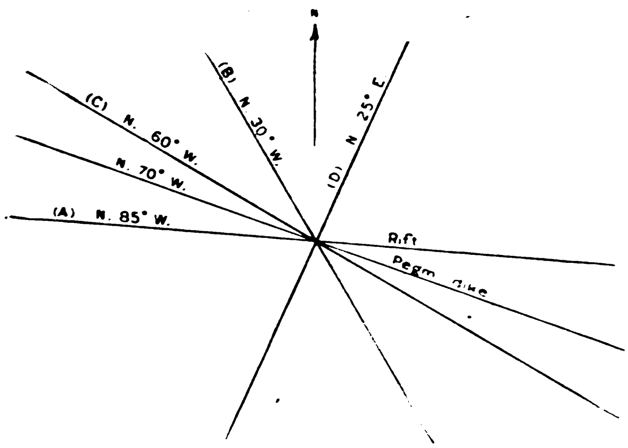

FIG. 24.—Structure at Long Cove quarry, Tenants Harbor.

strength made by the Columbia School of Mines are reported by the firm to have shown an ultimate crushing strength of 22,000 pounds per square inch, but the original report of these tests has been misplaced.

The quarry, opened about 1873, measures about 1,000 feet from north to south by 500 feet from east to west, and ranges in depth from 20 to 75 feet, averaging about 40 feet. Its drainage involves pumping with 4-inch pipe during rainy season. This is the only quarry in the State in which tunneling is resorted to in the use of explosives. (See p. 71.)

Rock structure: The sheets, from 6 inches to 13 feet thick, are horizontal, or dip 10°. Joints and dike courses are shown in fig. 24. A recurs at intervals of from 2 to 30 feet, B dips 25°, C dips 65° N. E. The east end of the quarry is much broken up by the closeness of joints A and the thinness of the sheets for a considerable distance below the surface. The rift is vertical with N. 80°–90° W. course. There is a horizontal dike of pegmatite up to 9 inches thick

at the north end of the quarry; another, divided into many parallel ones, strikes N. 70° W. and dips 70° N. These dikes all consist of white feldspar, quartz, muscovite, black tourmaline, and garnet. Sap occurs up to 18 inches thick along sheets and joints.

The plant consists of 1 derrick and 1 hoisting engine, 1 Blondin carrier, 1 locomotive crane, 1 compressor (capacity 560 cubic feet of air per minute), 3 steam drills, 3 pneumatic plug drills, and 1 steam pump.

Transportation is effected by inclined track 900 feet to wharf.

The product is used chiefly for monumental work, being specially adapted to rough face and fine work. It goes chiefly to Greenwood and other cemeteries near Brooklyn, N. Y. The small beds and waste are worked into paving blocks. Specimen buildings, etc.: Albany post-office, Bates Building, Philadelphia, and part of Saratoga monument.

THE QUARRIES OF VINALHAVEN AND HURRICANE ISLANDS.

These and the adjacent islands have been known collectively as the Fox Islands and their granite as Fox Island granite. The granite industry of these islands is distributed over an area about 5 miles from east to west by 4 miles from north to south. The locations of the quarries are shown on the map fig. 25. Some of them are near the center of Vinalhaven Island. The Palmer quarry is on the west shore; the Black and Webster quarries are on the east shore; the Sands, Harbor, and Armbrust quarries are on the south shore, near Vinalhaven village, while the Pequoit and Duschane Hill quarries lie east of the village near the east shore. There are some minor quarries ("motions") on Barton, Gundelow, and Green islands, and, finally, there is the important quarry on Hurricane Island. As will be seen from the descriptions, there is little difference between the coarse granites of the Hurricane Isle, Sands, Harbor, Armbrust, Black, Webster, and Palmer quarries, but the Duschane Hill and Pequoit quarry granites are fine textured, as is also that from an abandoned opening in Vinalhaven village.

Pl. II, *A*, shows the conspicuous east-west jointing in the granite on Heron Neck at the south end of Green Island. The same system of joints recurs on Hurricane Island and at the Sands and Armbrust quarries.

The Sands quarry is in the town of Vinalhaven, at the northeast side of the head of Sand Cove (see maps, Pl. I and fig. 25). Operator, Bodwell Granite Company; office, Rockland, Me.

The granite (specimen 1, *b*) is a biotite granite of general pinkish-buff, medium-gray color and of coarse, even-grained texture, the feldspars measuring up to three-fourths inch (rarely 1 inch) and the

biotite scales up to two-tenths inch. It consists, in descending order of abundance, of a pinkish-buff potash feldspar (chiefly orthoclase with some microcline), smoky quartz, milk-white soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite, zircon, and apatite. The orthoclase here and there contains irregular areas of carbonate, is intergrown with a plagioclase, or

FIG. 25.—Map showing location of quarries in Fox Islands. (From Vinalhaven sheet of Topographical Atlas of the United States, U. S. Geol. Survey.)

rimmed with oligoclase. The oligoclase is partially altered to kaolin and a white mica. Pyrite is found by the quarrymen in rare and minute particles, and molybdenite occurs occasionally in half-inch scales. Mr. E. C. Sullivan, of the United States Geological Survey, finds that this granite contains 0.034 per cent of CO_2 (carbon diox-

ide), and that warm dilute acetic acid extracts 0.07 per cent of CaO (lime), and a trace of MgO (magnesia). This, if the CO_2 is allotted to the CaO, shows a percentage of 0.08 of $CaCO_3$ (lime-carbonate), the presence of which mineral is also indicated by the microscope. The stone takes a fine polish, but the size of the mica plates does not favor the durability of the polished face under continued exposure. The contrasts of color and shade are chiefly between the two feldspars and the black mica.

The quarry, opened before 1860, now measures about 500 feet from northeast and north-northeast to southwest and south-southwest and about the same distance from northwest to southeast, and ranges in depth from 20 to 75 feet, averaging about 40 feet. The excavation has not only cut down a granite hillock, but has extended below the general land level. Pl. VI, *A*, shows the south-southeast end of the

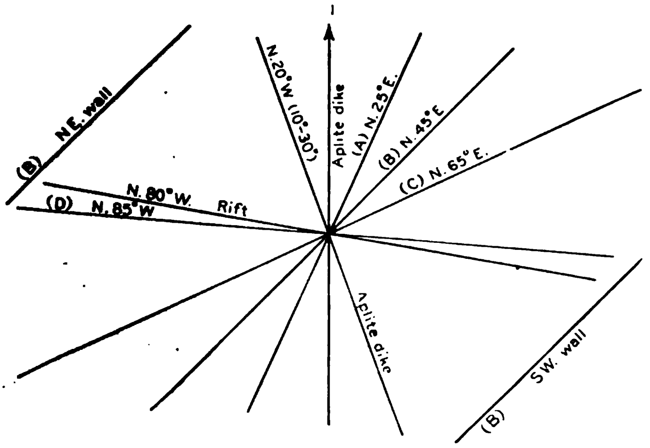

FIG. 26.—Structure at Sands quarry, Vinalhaven.

quarry. The surface drainage, as well as the water that exudes from between the sheets, is collected in the deeper, now unused parts of the quarry and supplies the boilers. No stripping seems to have been necessary.

Rock structure: The sheets, from 1 to 20 feet thick—generally, however, from 2 to 10 feet—lie flat along an east-west axis for a width of about 200 feet, but on either side curve over gently to the north and south, with dips of 5°, 10°, and 20°. The joint and vein courses are shown in fig. 26. Joints B form the northwest and southeast walls of quarry. Joints C are coated in places with crystalline calcite to the thickness of one-fourth inch, or with hematite, chlorite, and stilbite in microscopic films. (Determination of stilbite by Mr. W. T. Schaller, of the United States Geological Survey.) The rift is vertical, with a N. 80° W. course. The "hard-way" or

"cut-off" is N. 10° E. Blocks 65 and 120 feet long have been obtained by splitting along the rift. The thickness and curvature of the sheets, the intersecting joint face, and the channeling along the "cut-off" are shown in Pl. VI, *A*. Dikes of grayish aplite, described in detail on page 43, measure from 1 to 7 inches in thickness. There are occasional dark-gray knots (see p. 49 for description) of more biotitic granite, measuring up to 2 feet in length and 4 inches in width, and some of spheroidal form, with a diameter of 2½ feet. Sap is 4 inches wide on either side of joints A, B, D, and also along the sheet surfaces, but is there less marked. The unhewn weathered surface about the quarry passes into a granite sand, with little or no staining by limonite.

The plant consists of 5 derricks, operated by 3 engines, 2 surface traveling cranes (of 20 and 10 tons capacity), 2 Ingersoll & Sargent steam-driven compressors (each of 850 cubic feet per minute capacity), 4 large pneumatic drills, 8 pneumatic plug drills, 1 channeler, 8 surfacers, 6 polishers, 2 granite lathes (one for 30-foot columns, 5 feet in diameter, the other for small columns and balusters), 6 polishing lathes, 35 pneumatic hand tools, and several steam pumps.

Transportation is effected by railroad 500 feet long to wharf, which admits schooners of 200 to 800 gross tons capacity.

The product is used for docks, bridges, piers, buildings, and monuments. The thin sheets and much of the waste are made into paving blocks 12 by 4 by 7 to 8 inches. Pl. XIII, *A*, shows how the granite of this quarry lends itself to coarse sculpture. The principal markets are New York, Philadelphia, and Washington. Specimen structures made exclusively of Sands quarry granite: New post-office, Washington, D. C.; Masonic Temple, Philadelphia; savings bank, Wilmington, Del.; new board of trade building, Chicago; new post-office and custom-house, Brooklyn, N. Y.; Manhattan Bank, New York; General Wool monument, Troy, N. Y. The Sands quarry and the Palmer quarry together furnished all the stone for the new custom-house in New York.

In 1905 the following contracts were undertaken: The Altman Building, Thirty-fourth street and Fifth avenue, and the West Street office building, West, Cedar, and Albany streets, in New York, and some docks in the same city.

The Palmer or Wharf quarry, in the town of Vinalhaven, west side, opposite Leadbetter Island. (See map, fig. 25.) Operator, Bodwell Granite Company, Rockland, Me.

The granite (specimen 2, *b*) is a biotite granite of general pinkish-buff medium-gray color and of coarse texture, the feldspars measuring up to three-fourths inch and the biotite scales up to two-tenths inch. It is identical with that of the Sands quarry (see p. 129),

except that the potash feldspar is a little more pinkish buff and the white soda-lime feldspar is of a slightly greenish tinge. The general tone of the color is "warmer." The thin section shows rarely a little hornblende.

The quarry is on the west side of a 100-foot high ridge. It measures about 500 feet square and has an average depth of 25 feet. No stripping or pumping is necessary.

Rock structure: The sheets dip 10° W. in the front (western) part of the quarry, but gradually turn at the back or working face to 10° E. They range in thickness from 4 to 15 feet. About 20 feet below the top of the quarry face is a bed of granite sand, 18 inches thick, parallel to the sheets, already referred to on page 55. The principal joints strike N. 80° W. and dip 80° S., forming a 5-foot heading at the south end of quarry, and recurring but once or twice. The rift is vertical, trending N. 10° E. Owing to the structure here, it is usual to blast by lewis holes along the grain (east-west) and then to split by plug drilling along the rift; in this way thick sheets can be split along the grain a distance of 200 feet. One block loosened measured 300 feet along the grain by 120 feet along the rift and was 15 feet thick. Dikes of aplite are rare. A knot from this quarry is described in detail on page 49. Sap measures up to 6 inches in thickness along the sheet and joint surfaces. It is intense in color at the surfaces.

The plant consists of 5 derricks, 2 hoisting engines, 2 steam drills, 1 Ingersoll & Sargeant Duplex steam-driven air compressor (capacity, 525 cubic feet of air per minute), 1 channeler, 7 pneumatic plug drills, and 1 granite lathe, capable of carrying columns 70 by 7 feet, made by Cheney & Spiller, of Boston.

Transportation is effected by cartage of 700 feet to wharf, where the blocks are laden on schooners and taken either to the cutting sheds at the Sands quarry or directly to market.

The product is used chiefly for bridges and buildings, and the waste is made into paving blocks. This quarry, in common with the Sands quarry, furnished the material for the new New York custom-house. It supplied also 8 columns, 51½ to 54 feet long by 6 feet in diameter, for the cathedral of St. John the Divine in New York. It was intended that they should each be of one piece, but as both the direction of the rift at the quarry and architectural principles required that they be cut with their long axes at right angles to the rift, the strain in the great lathe came upon the weakest part of the stone. However, as the first stone put into the lathe broke with a long diagonal fracture, it became evident that the chief difficulty was that the stone had been subjected to too great a torsional strain by the application of rotary power from one end only. It therefore

became necessary to make each column of two sections, each about 26 feet long. Pl. XIII, *B*, shows the lathe with the first full-length column in it and three others as originally prepared for it.

The Webster quarry is in the town of Vinalhaven, on the north shore of "Pleasant River," at end of Winter Harbor, in the northern part of Vinalhaven Island. Operator, A. M. Webster & Co., Vinalhaven.

The granite is a biotite granite identical with that of the Palmer quarry, described on page 132.

The quarry, opened in 1899, is 150 feet N. 30° W. by 200 feet across and between 10 and 20 feet deep. The tide reaches its lower part. There are 2½ feet of stripping.

Rock structure: The sheets, from 5 to 10 feet thick, dip 10° to 15° N. 30° E. Vertical joints strike N. 30° W. and N. 60° E. The rift is vertical, with N. 30° W. course. There are some knots. A spherical one measures 5 feet in diameter. Sap is 3 inches thick along sheets and joints.

The plant consists of 3 derricks and 3 hoisting engines.

Transportation is effected on a graded track 200 feet to wharf that admits schooners of 300 to 350 long tons. Pl. XII, *A*, shows the quarry, and a schooner laden with granite.

The product is used for buildings in New York and Boston. It is shipped in the rough.

The Black (Pleasant River) quarry is in Vinalhaven town, on the south shore of Pleasant River, at end of Winter Harbor, in the northern part of Vinalhaven Island. Operator, Joseph S. Black, Vinalhaven.

The granite is a biotite granite, identical with that of Webster quarry and Palmer quarry, described on page 132.

The quarry, opened in 1896, measures 300 feet in a N. 40° W. direction by 200 across and has a working face 45 feet high. The drainage is used to supply the boiler. There is 1 foot of stripping in places.

Rock structure: The unworked surface above the quarry is very free from joints, knots, and veins. The sheets, from 10 to 12 feet thick, are horizontal at the working face or back of the quarry, but at the front dip 10°–15° W. Vertical joints strike N. 20° E. The rift is vertical, with course N. 40° W. Knots are from 6 inches to 2 feet 6 inches in diameter. No dikes.

The plant consists of 3 derricks, 2 engines, and 2 steam drills.

Transportation is effected by a 350-foot track, with a grade of 10 feet to wharf.

The product is used for building, the waste for riprap. It is marketed in New York, Philadelphia, and Boston. The quarry has

furnished material for the dry dock at Portsmouth, N. H., and the Rain Island light-house. In 1905 it was supplying blocks for a private residence at Gladstone, N. Y.

The Pequoit quarry is in the town of Vinalhaven, 1¼ miles east-northeast of Vinalhaven village, on Vinalhaven Island. Operator, Booth Brothers & Hurricane Isle Granite Company, Rockland, Me.

The granite (specimen 7, *a*) is a biotite-hornblende granite of medium-gray shade and fine even-grained texture, with porphyritic feldspars up to one-fourth inch in length. It consists, in descending order of abundance, of a whitish, translucent potash feldspar (orthoclase, with a very little microcline), smoky quartz, a whitish soda-lime feldspar (oligoclase), black mica (biotite), and dark hornblende, together with accessory magnetite, titanite, apatite. The orthoclase is here and there intergrown with a plagioclase. The orthoclase is in places altered to kaolin and a white mica and includes occasionally some carbonate. The porphyritic crystals are orthoclase.

The quarry, opened in 1887, consists of two openings, each about 250 feet square and about 10 feet deep. Drainage is effected by a 2-inch siphon, 240 feet long.

Rock structure: The sheets, from 1 to 6 feet thick, dip 10°–15° N. 80° W. Vertical joints strike N. 80° W. and N. 5°–10° E. The rift is vertical, striking N. 5°–10° E.

There is no machinery. The product is carted one-third mile to the narrows and there shipped.

The product consists entirely of paving blocks (10 to 14 by 4 to 5 by 6 to 7 inches) which go to New York and Philadelphia. In 1905 an order was being filled for New Jersey.

The Duschane Hill quarry, in the town of Vinalhaven, 1¼ miles east of Vinalhaven village, on Roberts Harbor. Owned by Bodwell Granite Company, but no longer operated. Office, Rockland, Me.

The granite (specimen 8, *a*) is a biotite granite of medium buff-gray color and of fine to medium porphyritic texture, with most of the feldspars about one-fifth inch long, but some one-third or one-half inch long. The rock consists, in descending order of abundance, of a buff-gray potash feldspar (orthoclase), smoky quartz, a buff-gray soda-lime feldspar (oligoclase), and black mica (biotite), together with secondary chlorite. The orthoclase is intergrown with plagioclase and the oligoclase is partly altered to kaolin and a white mica.

This stone was used for paving blocks.

The Armbrust quarry is in the town of Vinalhaven, between Carvers Harbor and Indian Creek, south of Vinalhaven village. Operator, J. P. Armbrust, Crown Hill Granite Works. Office, Vinalhaven.

The granite is a biotite granite similar to that of the Sands quarry described on page 129.

The quarry consists of numerous openings on several sides of a hillock 100 feet high.

Rock structure: The sheets, 3 to 15 feet thick, are horizontal, but on the east side of the hill dip 10° S. Vertical joints strike N. 75°–80° W., and also N. 30°–35° E. There is no marked rift, but a vertical mass 4 feet thick, striking N. 65° W. across the hill, has a horizontal rift and greatly facilitates quarrying, as it serves the purpose of a channel.

The plant consists of 3 hand derricks, 2 steam derricks, 1 horse derrick, and 3 big wagons. Pl. XII, *B*, shows the character of this work.

Transportation: The product is carted in 7 to 10 ton loads one-fourth to one-half mile to wharf on Carvers Harbor.

The product consists entirely of paving blocks, which find a market in New York, Newark, and Philadelphia.

The Harbor quarry is in the town of Vinalhaven, on the east side of Sand Cove, near Vinalhaven village. Operator, Bodwell Granite Company, Rockland, Me.

The granite is a biotite granite like that of the Sands quarry, described on page 129, but is harder and is therefore discarded for structural uses and employed only for paving, according to demands.

The quarry is about 450 feet from northeast to southwest by about 300 feet from northwest to southeast and from 10 to 40 feet deep.

The sheets, from 2 to 5 feet thick, lie horizontal on the top of the hill, but dip southeast and northwest up to 15° at the sides. The joints are like those at the Sands quarry (fig. 26), but an additional set strikes N. 25° W.

The Bodwell black-granite openings are in the town of Vinalhaven, in the diabase area west of Sand Cove. Operator, Bodwell Granite Company, Rockland, Me.

This rock (specimen 1½, *a*) is an olivine norite, of almost black color and of fine texture, consisting, in descending order of abundance, of a network of usually slender crystals (from 0.37 to 1.66 mm. in length) of grayish unaltered lime-soda feldspar (labradorite to bytownite) filled with hypersthene, greenish olivine, black mica (biotite), and magnetite. It takes a very fine polish and cuts white. It is not obtainable in very large blocks. This stone is referred to by George P. Merrill.[a]

The Gundelow quarry is on Gundelow Island, south of Barton Island, west of Vinalhaven Island. It produces paving blocks, but was not in operation in 1905.

The George Gins quarry is at the north end of Green Island, between Vinalhaven Island and Hurricane Island. It produces paving

[a] Tenth Census, vol. 10, p. 24.

blocks, but was reported as not in operation in 1905 and was not visited by the writer. The product of this quarry is purchased by Booth Brothers & Hurricane Isle Granite Company.

The Hurricane Island quarry is in the town of Vinalhaven, in the southeast part of Hurricane Island. (See map, fig. 25.) Operator, Booth Brothers & Hurricane Isle Granite Company; office, 207 Broadway, New York, and Rockland, Me.

The granite (specimen 4, *a*) is a biotite granite of general pinkish-buff, medium-gray color, and of coarse, even-grained texture, the feldspars measuring up to three-fourths inch and the biotite scales up to two-tenths inch. It is identical with that of the Sands quarry, described on page 129. The potash feldspar is perhaps a trifle more pinkish buff than that of the Sands quarry, but not quite so much so as that of the Palmer quarry. These distinctions, however, are small, and may not hold throughout the quarries, although they do characterize the typical specimens selected for the writer by the superintendents of the respective quarries.

The following chemical analysis of Hurricane Island granite was made by Ricketts & Banks, of New York, for the firm (No. 16073), and is inserted here for reference merely.

Analysis of granite from Hurricane Island.

	Per cent.
SiO_2 (silica)	70.94
Al_2O_3 (alumina)	15.68
FeO (ferrous oxide)	2.29
CaO (lime)	1.23
MgO (magnesia)	0.19
MnO (manganese oxide)	0.13
Na_2O (soda)	3.58
K_2O (potash)	5.54
S (sulphur) total	0.05
CO_2 (carbon dioxide)	None.
Loss and undetermined	0.37
	100.00

The following compression test was made by Prof. Ira H. Woolson, of the Columbia School of Mines.[a] Ultimate crushing strength, 19,583 pounds per square inch.

The quarry, opened about 1876, measures 500 feet along the rift (N. 85° W.) and has an average width of 150 feet. It lies on the south side of a ridge 100 feet high with a west-northwest to east-southeast axis. The greatest depth of working face is 105 feet, and its average is about 50 feet. The drainage is saved to supply the boilers. There is no stripping.

[a] Published by William C. Day in Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, continued, 1899, p. 391. (Test No. 1709.)

Rock structure: The sheets, from 3 to 20 feet thick, curve over on both the north and the south side of the ridge, with a dip of not less than 10°. Seen from the western spur of the island, two 20-foot sheets form the upper part of the hill; beneath these, however, is a much thicker sheet, which at the east-southeast end of the hill and quarry measures fully 60 feet—too thick for economic working. These sheets are shown in Pl. IV, *A*, as seen looking northwest. This abnormally thick sheet is referred to by Merrill.[a] The sheets are traversed by three sets of joints, as shown in figure 27. A dips 50° to 55° W.; B is vertical, and C, which is diagonal to A and B, dips 40° NE. The rift is vertical, with N. 85° E. course. The east-west system (B), which is parallel to the rift, reappears on Heron Neck, as shown in Pl. II, *A*. B and C are both shown on Pl. IV, *A*.

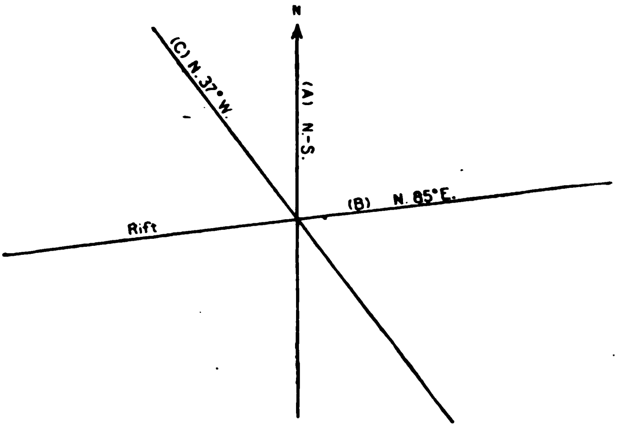

FIG. 27.—Structure at Hurricane Island quarry, Knox County.

The B surfaces are, in places, coated with epidote. Occasional knots occur.

The plant consists of 8 derricks, run by 5 engines; 2 traveling steam cranes, 1 compressor (with capacity of 900 cubic feet of air per minute), 1 channeler, 6 steam drills, 23 pneumatic plug drills, 7 surfacers, 5 polishing lathes (2 small and 3 for stones, 30 feet by 5 feet), 1 steel saw for sawing granite with chilled iron shot, 32 pneumatic hand tools, and 2 steam pumps.

Transportation is effected by track, 400 feet long, to dock.

The product is used for buildings and monuments. The waste goes into paving blocks. The chief markets are New York, Philadelphia, and the interior. Specimen buildings: The Suffolk County court-house at Boston; the St. Louis post-office and custom-house; two buildings for the Naval Academy at Annapolis, Md.

[a] Ann. Rept. Smithsonian Inst., pt. 2, 1889, p. 415.

LINCOLN COUNTY.

The quarries in Lincoln County are in the towns of Bristol, Waldoboro, and Whitefield.

The Round Pond quarry is in the town of Bristol, one-fourth mile east of Round Pond village, and west of Muscongus Island. Operator, Peter Swensen & Co., Round Pond, Me.

The rock (specimens 126 *a*, 126 *b*) is a quartz diorite of very dark gray and medium-gray shades and of fine, even-grained texture, with feldspars up to one-fifth inch. The darker variety consists, in descending order of abundance, of bluish-white soda-lime feldspar (oligoclase-andesine), clear quartz, black mica (biotite), potash feldspar (orthoclase and microcline), and magnetite, together with accessory titanite, zircon, apatite, and secondary calcite. The lighter consists of the same minerals, but with less biotite, so that it changes place with the potash feldspar in order of abundance. Both varieties take a fine polish and offer a very marked contrast between the polished and cut or hammered surface. Granite of the same shade affords no such contrast.

The quarry, opened in 1885, consists of two adjacent openings along a northwest-southeast line. The upper or northwestern one is 100 feet square; the lower is 400 feet (northwest-southeast) by 100 feet across, but with a central part 37 feet wide on each side—that is, 175 feet wide. These openings range in depth from 10 to 65 feet. Drainage is natural, the excavations not having gone below high-tide level.

Rock structure: Considerable scientific interest attaches to the geological relations at this quarry, as may be seen by the references to them on pages 44, 48, 60–62. This quarry has been described by J. E. Wolff.[a] The diorite underlies a mass of schist which strikes N. 15° E., and is traversed by dikes and lenses of coarse pegmatite. It also includes a tongue of this schist, as shown in Pl. XI, *B*, and is traversed by dikes of pegmatite, as shown in Pl. X, *B*, and XI, *A*, and itself, in turn, is traversed, as is also its pegmatite, by a diabase dike. Thus the schists are older than the diorite, and the dike is later than the diorite and its pegmatite. The joint and dike courses are shown in fig. 28. The sheets, from 1 to 12 feet thick, dip 10° south and also 10° east, and are traversed by joints A, which recur at intervals of 5 to 42 feet, and B, which recur but once or twice. There are bad headings on the northeast side of the quarry. The pegmatite dikes send out small branches. Sap, only 1 inch thick, occurs along the sheets. Knots measure up to 6 by 2 inches, but are rare. These sheets, joints, and dikes are shown in the plates referred to. The general result of this complex structure is that it is difficult to obtain many large blocks.

[a] Details of Maine granite quarries: Tenth Census, vol. 10, 1888, p. 121.

The plant consists of 3 derricks, worked by oxen, and 2 steam polishers.

Transportation is by cartage of about 300 feet from the lower quarry, and of possibly 800 to 1,000 feet from the upper one, to the wharf in Muscongus Bay.

The product is now used exclusively for monuments, and finds a market in New York, Pennsylvania, and the West. The waste goes into paving blocks.

Specimen monuments: The die of the Maine monument at Andersonville, Ga.; the base and die of the General Sheridan monument in the National Cemetery at Arlington, Va.

In 1905 finished monuments were being sent to New York, where the lettering was added.

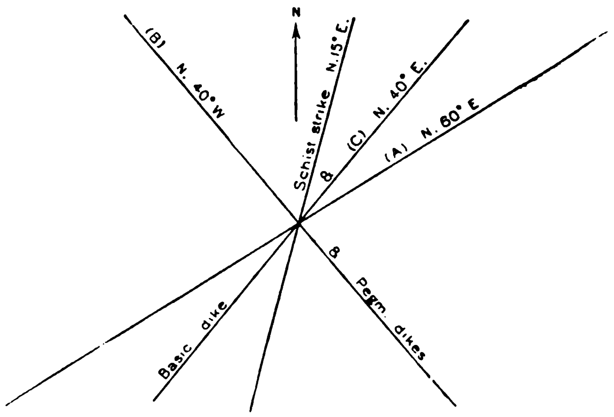

FIG. 28.—Structure at Round Pond diorite quarry, Bristol.

The Waldoboro quarry is in the town of Waldoboro, 1½ miles north of Waldoboro village, on the Boston and Maine Railroad. Operator, Booth Brothers & Hurricane Isle Granite Company, 207 Broadway, New York, and Rockland, Me.

The granite (specimen 109, *a*) is a muscovite-biotite granite of medium-gray shade (a trifle darker than Hallowell granite, and still darker than North Jay granite) and of fine (inclining to medium) even-grained texture, some of the feldspars measuring up to one-fourth inch, but the particles generally ranging from 0.36 to 2.56 mm. in diameter. It consists, in descending order of abundance, of a whitish translucent potash feldspar (orthoclase and microcline), smoky quartz, whitish soda-lime feldspar (oligoclase), white mica (muscovite), and black mica (biotite), with accessory garnet. The feldspars are often intergrown with quartz in particles that are circular in cross-section. Some of the mica plates are bent, indicating slight (secondary) motion. Mr. E. C. Sullivan, of the United States

Geological Survey, finds that this granite contains 0.045 per cent of CO_2 (carbon dioxide) corresponding to a content of 0.10 per cent of $CaCo_3$ (lime carbonate), and that warm dilute acetic acid extracts from it 0.11 per cent of CaO (lime). This granite contains sporadic particles or crystals, up to one-fourth or even one-half inch in diameter, of a milk-white mineral, which weathers readily, becoming yellowish and powdery, and finally leaves cavities. Dr. George P. Merrill, head curator of geology at the United States National Museum, has examined this mineral, and finds it to be a feldspar lying between albite and oligoclase—that is, containing between 6 and 11 per cent of soda, therefore a little more soda than the soda-lime feldspar of the granite itself, which is 5 to 5.5 per cent, and that the powdery material is very near kaolin. But he does not regard his results as perfectly satisfactory, nor does he understand why such a feldspar should weather so readily. The slightly higher percentage of soda indicated does not seem to him an adequate cause for the weathering, although minerals rich in soda do weather with comparative facility. Workmen report that when first decomposing this mineral protrudes beyond the granite surface.

The following analysis of the granite was made by Ricketts & Banks, of New York, for the firm (No. 16074), and is given merely for reference:

Analysis of granite from Waldoboro quarry.

	Per cent.
SiO_2 (silica)	73.48
Al_2O_3 (alumina)	15.26
FeO (ferrous oxide)	1.42
CaO (lime)	0.88
MgO (magnesia)	0.09
MnO (manganese oxide)	0.10
Na_2O (soda)	3.12
K_2O (potash)	5.66
S (sulphur) total	Trace.
CO_2 (carbon dioxide)	None.
	100.01

The following test of compressive strength of Waldoboro granite was made by Prof. Ira H. Woolson of the Columbia University School of Mines:[a] Number of test, 1714; crushing strength, 23,111 pounds per square inch.

The quarry, which was opened in 1860, measures 400 (N. 52° E. to S. 52° W.) by 140 feet across, and is of 60 to 85 feet deep. Its drainage requires pumping for about two hours a day and this supplies the boilers. There is no stripping.

[a] Published by William C. Day in Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, continued (1899), p. 391.

Rock structure: The geological relations at this quarry are of no little interest, as will be seen by the references to it on pages 15, 45, and by Pl. IX, *A*, and fig. 29. The granite is here in contact with the schist mass, which originally covered it and which at all the other Maine quarries, except those at Freeport and Round Pond, has been removed. On the northeast side of the quarry a mass of schist striking N. 72° W. and dipping 45° N. 72° E. and also 90°, overlies the granite, which sends small dikes into it. The contact between the two rocks appears at the east corner of the quarry and is shown in Pl. IX, *A*. At the southwest end of the quarry two schist masses are partially included in the granite, and a large pegmatite mass intervenes, as is shown roughly in fig. 29. The sheets, from 1 to 7 feet thick, lie horizontal and dip 5° W. in the upper part of quarry. The joint and dike courses are shown in fig. 30. Joints A dip 60°

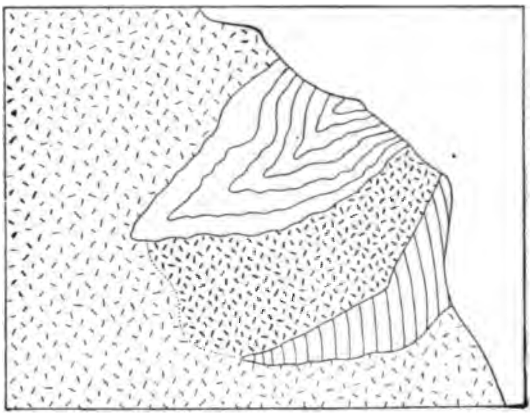

FIG. 29.—Schist inclusions at southwest end of Waldoboro quarry. Total height, 45 feet. The coarse material, between the two inclusions, is pegmatite. The finer is muscovite-biotite granite.

SE., and form both longitudinal walls of the quarry, a heading on the northwest side, and recur at intervals of 40 feet. Joints B dip 85° N. and recur at intervals of 100 feet. The rift is horizontal and the grain is vertical, with course N. 60° W. Pegmatite dike *a*, 5½ inches thick, dips 60° SE.; dike *b*, 12 inches thick, dips S. 60° W., at an angle of 45°. A dike of aplite, an inch thick, dips 45° NE. Sap is confined to the upper sheets. Knots are very exceptional.

That the granite is under compressive strain is shown by the closing up of the channels when the cores are taken out, and also by spontaneous north to south fissuring.

The plant consists of 3 derricks, operated by 3 engines (one of these derricks is 108 feet 4 inches high with a 90-foot boom), 3 overhead traveling cranes (of 3 and 2 tons capacity), 1 compressor (ca-

pacity about 400 cubic feet of air per minute), 3 large steam drills, and 1 small one, 14 pneumatic plug drills, 6 surfacers, 23 pneumatic hand tools, and 2 steam pumps (5 inch and one-half inch).

Transportation is effected by cartage 1,300 feet (and 120 feet down) from quarry to mill, then by cars 19 miles to wharf at Rockland. The distance from quarry to tidewater at Waldoboro is only 1½ miles, but the water there is only 11 feet deep at high tide.

The product is used for buildings and monuments, but not for polished work. The small sheets and waste are used for paving and road ballast. About 250,000 paving blocks are shipped annually, mostly to Philadelphia. The chief markets for this stone are New York and Philadelphia. Specimen buildings: The Buffalo Savings Bank, the armory, boat house, and cadets' quarters at the United States Naval Academy, Annapolis, Md.; the Crockett monument at

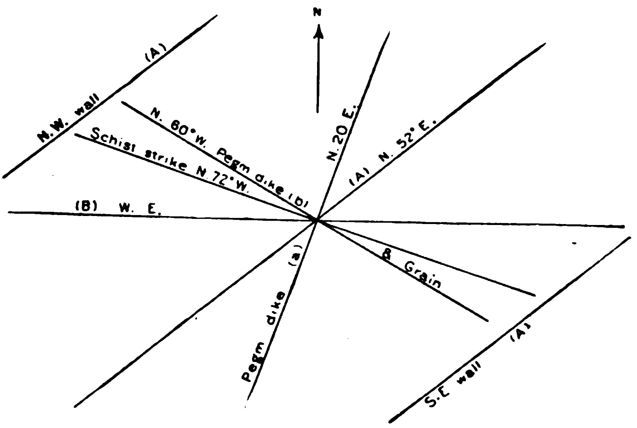

FIG. 30.—General structure at Waldoboro quarry.

Acorn Cemetery, Rockland, Me. Contracts in 1905: The Chemical National Bank in New York; "platforms" for sidewalk around Schwab Building, Seventy-fourth street and Riverside Drive, New York. In September, 1905, two fluted columns, 25 feet long, were being cut for a block in New York, and some fine carving on keystones, etc., for one of the buildings at the United States Naval Academy.

Jewett's black-granite quarry is in the town of Whitefield, 1½ miles southeast of Whitefield village (Kings Mills). Operator, E. C. Jewett, Whitefield, Me.

The rock (specimen 113, *a*) is a quartz diorite of very dark gray shade with a bluish tinge, and of fine to medium even-grained texture and flow structure, with feldspars up to one-fourth inch in diameter. It consists, in descending order of abundance, of bluish milk-

white soda-lime feldspar (oligoclase-andesine), black hornblende, quartz in amount almost, if not quite, equal to that of the hornblende, black mica (biotite), and accessory magnetite, titanite, zircon, apatite, and secondary epidote. The stone takes a fair polish.

The quarry, which was opened in 1885 for monumental work, consists of two adjacent openings, one 50 by 25 feet and up to 6 feet in depth; the other 60 by 30 and 5 to 8 feet in depth, besides 4 feet of clay loam stripping.

Rock structure: The sheets, 3 to 8 feet thick, dip 25°–30° NE. Vertical or steep joints strike N. 10° W. and N. 42° W. The rift is vertical with N. 10° W. course, and the grain is parallel to the sheets. The sap is 3 inches thick along the joints. There is one aplite dike 2¼ to 4 inches thick. Biotite knots occur occasionally.

The product is used for monuments locally.

OXFORD COUNTY.

The granite quarries in Oxford County are in the towns of Fryeburg, Oxford, and Woodstock.

The Eagle Gray quarry is in the town of Fryeburg, at the northeast foot of Starks Hill, about 1¼ miles south of Fryeburg village. Operator, Eagle Gray Granite Company, Fryeburg, Me.

The granite (specimen 124, *a*) is a muscovite-biotite granite of general medium even-grained texture, with feldspar one-fourth inch in length and mica up to one-fifth inch. It consists, in descending order of abundance, of slightly cream colored potash feldspar (orthoclase), smoky quartz, slightly cream colored soda-lime feldspar (oligoclase), white mica (muscovite), and black mica (biotite), together with accessory garnet and zircon. The contrasts are chiefly between the cream-colored feldspar and the smoky quartz and the brilliant muscovite plates. The large size of the mica plates is unfavorable to the durability of its polish under outdoor exposure.

The quarry, opened in 1903, is about 150 feet square by 3 to 12 feet deep.

Rock structure: The sheets, from 1 to 10 feet thick and becoming thicker southwest, dip less than 10° NE. There are no joints, but there are several pegmatite and diabase or basalt dikes, already referred to on page 45 and shown in fig. 31. These generally have a northwest-southeast course. The pegmatite is very coarse, affording incomplete crystals of orthoclase 1 foot long and biotite crystals 3 inches long. Mingled with the pegmatite are irregular bands of whitish garnetiferous aplite. The absence of joints and the abundance of dikes are the chief obstacles here. The rift is horizontal and marked, but there is no grain. Sap, one-half inch thick, is confined to the top sheet.

The plant consists of 2 hand derricks.

Transportation is by cartage two-fifths mile to Maine Central Railroad.

The product is used for buildings and for bases to monuments, and finds a market at widely scattered points in the West and South. Specimen building: The granite part of the Conway, N. H., public library. In 1905 the quarry was supplying bases to private monuments.

The Hodsdon quarry is in the town of Fryeburg, at the northeast foot of Starks Hill, a little over 1¼ miles south of Fryeburg village. Operator, W. I. Hodsdon, Brownfield, Me.

The granite (specimen 125, *a*) is a muscovite-biotite granite of general medium-gray shade and medium even-grained texture, identical with that of the Eagle Gray granite quarry described on page 144.

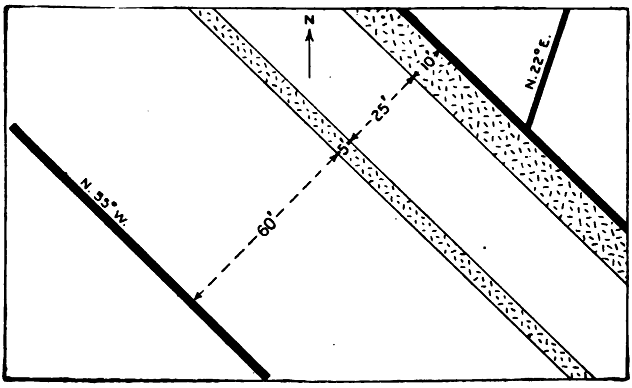

FIG. 31.—Structure at Eagle Gray quarry, at Fryeburg. The black bands are basic dikes, and those with a pattern are pegmatite.

The quarry, opened in 1905, measures 120 by 30 feet and averages 8 feet in depth. The stripping is less than 2 feet.

Rock structure: The sheets, from 1 to 4 feet thick, dip 10° NE. but taper, "growing on." There are no joints but 3 vertical basic dikes, from 16 to 24 inches wide, with courses of N. 30° W., N. 30° E., and N. 70° E. The rift is horizontal and the grain is vertical, trending north-south. Sap is confined to a space of several feet on each side of the dikes. Knots are infrequent.

The plant consists of 3 derricks.

Transportation involves a cartage of about one-half mile to Maine Central Railroad.

The product is used for bases of monuments, curbing, and paving blocks, and finds a market mostly within the State.

The Roy quarry is in the town of Oxford, three-fourth mile from Oxford village. Operator, Elie Roy; office, 94 Chestnut street, Lewiston, Me.

The granite (specimen 121, *a*) is a muscovite-biotite granite of medium cream-gray color and of medium (inclining to coarse) even-grained texture, with feldspars up to four-tenths inch in diameter. It consists, in approximate descending order of abundance, of a cream-colored potash feldspar (orthoclase and microcline), smoky quartz, cream-colored soda-lime feldspar (oligoclase), white mica (muscovite), and black mica (biotite), together with accessory apetite. Some of the joint planes are coated with coarse fibrous muscovite in parallel arrangement.

This quarry, opened in 1898, covers about 5 acres and has a working face 40 feet deep. It is worked only occasionally. The product is used for rough foundations and also for trimmings. The trimmings on the Catholic Church at Berlin, Me., and the McGillicuddy Block at Lewiston are of this granite.

The Bryant Pond quarry is in the town of Woodstock, one-half mile south of Bryant Pond station, on east side of the Grand Trunk Railway. Operator, Grand Trunk Railway; address, Master of Bridges and Buildings, Grand Trunk Railway, Montreal, Canada.

The rock (specimen 122, *a*) is a quartz diorite with conspicuous black particles on a more bluish-white rather than a yellowish-white ground, and of medium even-grained texture and flow structure, with feldspars and black minerals up to three-tenths inch in diameter (rarely four-tenths). It consists, in descending order of abundance, of white translucent soda-lime feldspar (oligoclase to oligoclase-andesine), clear quartz, black mica (biotite), and black hornblende, together with accessory garnet, titanite, zircon, apatite, and a little secondary epidote. Some of the feldspars are partially altered to a white mica and some have borders that are radially intergrown with quartz.[a] The clearness of the quartz and the translucent whiteness of the feldspar result in the apparent merging of the two minerals, and as the biotite and hornblende are both black the only contrast in the rock is that between black and white. There is a marked contrast between the hammered and rough surface, which is attributable to the presence of soda-lime feldspar alone. (See p. 59.) The flow structure, where marked, gives the rock a gneissoid aspect.

The quarry, opened about 1864, is 150 feet from north to south by 250 feet from east to west and from 10 to 50 feet deep. It is on the west side of a north-south ridge. There is no drainage problem. The stripping consists of 5 to 12 feet of bowlder drift.

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[a] Michel Lévy's "structure vermiculée: Bull. Carte géol. de France, No. 36, vol. 5. 1893-4, pp. 27-28, fig. 5.

Rock structure: There is a marked flow structure in places horizo tal and parallel to the rift, but in others quite irregular. The sheet from 1 to 6 feet thick, are horizontal or slightly undulating on tl quarry face, but at the west side dip 20° to 30° west. They increa in thickness downward and at the bottom of the quarry appear to ru out ("grow on"), making quarrying in that direction increasing difficult. A vertical joint, striking N. 35° E., is coated with crysta line calcite and epidote. The rock adjacent to it for an inch or tv contains much pyrite and also chlorite, probably derived from alte ation of hornblende. The rift is horizontal and the grain vertic north-south, but disappears on the west side. Vertical basalt or di base dikes, with northeast-southwest courses, form the north ar south walls of the quarry, 4 feet and 22 inches thick, respectively. 5-inch one occurs 25 feet north of the south wall. A thin section a half-inch branchlet from this dike is described on page 48. Sap confined to the upper sheets. There are some knots.

The plant consists of 3 derricks and 1 hoisting engine.

Transportation: Derricks lift the blocks from the quarry to tl cutting shed and from that to the cars of Grand Trunk Railway.

The product is used entirely for bridges and stations on the Grai Trunk Railway. Specimen buildings: The vestibule, first story, ar trimmings of Grand Trunk Railway station at Portland, Me.; tl Grand Trunk Railway station at Battle Creek, Mich.

PENOBSCOT COUNTY.

The quarries in Penobscot County are in the town of Hermon.

The Hermon Hill quarry is on Hermon Hill, 5½ miles northwe of Bangor. Operator, Dr. H. F. Hanson, Bangor, Me.

This black granite (specimen 106, *c*) is an altered diabase po phyry of dark-green color and fine texture, with porphyritic cry tals of black hornblende up to three-fourths inch in diameter. Tl rock consists, in descending order of abundance, of hornblende, ca cite, a much-altered feldspar (plagioclase), and magnetite, togeth with secondary actinolite, fibrous serpentine, and chlorite. It co tains sufficient calcite (lime carbonate) to make it effervesce wi cold dilute hydrochloric acid. It takes a very fine polish and cu very light, but the presence of the calcite exposes it to attack by tl carbonic acid of the atmosphere. It is therefore more suitable f indoor work. Ora W. Knight, State assayer of Maine, reports th it contains a very small amount of platinum, which is very irreg larly and unevenly distributed.[a]

The quarry, opened in 1900, measures 25 by 20 feet and from to 12 feet in depth.

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[a] Letter addressed to Doctor Hanson October 3, 1905.

Rock structure: The outcrop is about 200 feet from northeast to southwest by 40 to 50 feet across, and occurs in a chloritic-quartzose shale, striking N. 45° E. In places, however, there intervenes a granite porphyry containing crystals of orthoclase largely altered to muscovite, chlorite, and biotite. The sheets are from 6 inches to 6 feet thick and dip S. 60° E. at an angle of 30°. Vertical joints strike N. 60° W., forming a heading on the northeast, and recur at 20-foot intervals, also striking N. 20° W. and spaced from 2½ to 8 feet. Both the above show marks of slippage. There is also a diagonal set striking N. 45° W. and dipping 45° SW., recurring irregularly. The rift seems to be parallel to the sheets. Sap occurs along the joints. There are quartz veins parallel to the sheets and rift.

There is no machinery.

Transportation involves cartage of 1 mile to the new Maine Northern Seaport Railroad, or 5½ miles to Bangor.

The quarry is worked only occasionally.

The product is used for dies, memorial tablets, and wainscoting. Specimen monuments: Die on soldiers' monument at Hermon; about 20 dies in Mount Hope and Mount Pleasant cemeteries at Bangor; dies at cemetery at Springfield, Me.; cornerstone of Catholic Church at Orono; keystone, etc., at Lord Hall at University of Maine.

PISCATAQUIS COUNTY.

One quarry in Piscataquis County is in the town of Guilford.

The Queen City Granite quarry is 3½ miles from Foxcroft. Operator, Queen City Granite Company; office, Oak street, Bangor, Me.

The granite (specimen 107, *a*) is a biotite-muscovite granite of light-gray shade and medium to coarse, even-grained texture, with feldspars up to one-half inch in diameter and biotite scales up to 0.15 inch. It consists, in descending order of abundance, of very slightly bluish white potash-feldspar (microcline), smoky quartz, a whitish soda-lime feldspar (oligoclase), black mica (biotite), and much less white mica (muscovite), together with accessory magnetite. The oligoclase is partly altered to a white mica. As the feldspars are of similar shade and the muscovite is present in small amount the contrasts are between the feldspar, smoky quartz, and biotite, and they are marked.

The quarry measures 100 by 50 feet and has a maximum depth of 70 feet, the average being about 35. It had not been worked for two years.

The stone is used for building. The trimmings of a brick building erected in 1899 for Bangor Theological Seminary and those of the Stetson Block at Bangor are made of it.

SOMERSET COUNTY.

The granite quarries in Somerset County are in the towns of Hartland and Norridgewock.

The Hartland quarry is in the town of Hartland, near Hartland village, on the Sebasticook and Moosehead Railroad. The quarry was not operated in 1905, but was formerly operated by Joseph H. Baker. Property reported as owned by the Linn estate.

The rock (specimen 141, *a*, collected by Dr. George Otis Smith), is a quartz diorite with conspicuous black particles on a more bluish than yellowish white ground, and of medium to coarse, even-grained texture with flow structure. It consists, in descending order of abundance, of a translucent milk-white soda-lime feldspar (oligoclase), very slightly smoky quartz, black mica (biotite), black hornblende, and accessory titanite and magnetite. Some of the feldspars are cloudy from incipient alteration.

The Dodlin quarry is in the town of Norridgewock, on the northeast side of Dodlin Hill, which lies 2½ miles south of Norridgewock village, and has a north-northeast-south-southwest axis and a height of 350 feet above the general level and of 650 feet above sea level. Operator, Dodlin Granite Company; office, Oakland, Me.

The rock (specimens 116, *a*, and 116, *b*) is a quartz monzonite of two shades. Specimen 116, *a*, is a general medium gray with conspicuous black particles on a white ground, and specimen 116, *b*, is a general light gray with much finer black particles on a ground of mixed white and gray. Both rocks have a like texture, medium inclining to fine, with porphyritic crystals of white feldspar up to one-half inch. In the darker rock (116, *a*) the biotite scales measure up to one-tenth inch, while in the lighter they rarely attain one-twentieth inch. Both varieties consist, in descending order of abundance, of a slightly bluish milk-white soda feldspar (oligoclase) and, in equal or slightly less amount, of a whitish potash feldspar (microcline), quartz, almost clear in the darker rock (116, *a*) and light smoky in the lighter one (116, *b*), and black mica (biotite) (considerable in 116, *a*, but much less in 116, *b*), with accessory magnetite, titanite, zircon, pyrite, and secondary epidote and white micas. Some of the feldspars are radially intergrown with quartz.[a] In the darker variety, owing to the clearness of the quartz and the abundance and coarseness of the biotite, the contrast is simply between the black mica and the white feldspar, but in the lighter variety, owing to the smokiness of the quartz and the smallness of the biotite scales, the contrast, although not very marked, is between the gray quartz, white feldspar, and black mica.

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[a] "Structure vermiculée" of Michel Levy: Bull. Carte géol. de France, No. 36, vol. 5, 1893–4, pp. 27–28, fig. 5.

The quarry, opened about 1885, measures 400 feet from north-northwest to south-southeast by 250 feet across, and has an average depth of 30 feet. There is no drainage problem. Stripping up to 4 feet thick.

Rock structure: There is a vertical northeast-southwest flow structure indicated by the dividing line between the dark and light granite (shown in diagram sketch of upper part of quarry, fig. 32), and also in the light and dark banding of some of the lower sheets. The sheets, from 2 inches to 16 feet thick, dip about 5° E. In the south part of the quarry they measure up to 2 feet only, but in the northern part from 2 feet to 16 feet. Joint and dike courses are shown in fig. 33. A recurs at intervals of 200 feet. From the relation of the thickness of the sheets to the joint spaces, both in this quarry, as shown in fig. 32, and in two adjacent abandoned openings, known as the " Mink Hole " and " Bank quarry," it appears that in

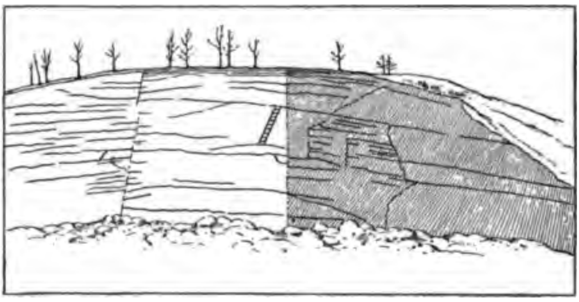

FIG. 32.—Diagram sketch showing junction of light and medium gray granites (quartz monzonites) and the lateral change in thickness of sheets at the Dodlin quarry, near Norridgewock.

places thin sheets, in others thick sheets, continue downward in alternating vertical zones, and that thin sheets are also apt to occur on both sides of the vertical joints for a few feet. These relations, which are very exceptional in the Maine quarries, may be due to vertical faulting. A horizontal displacement of a foot in a vertical flow-structure band was detected in the working face, evidently due to faulting at right angles to that just referred to. The rift is horizontal—that is, at right angles to the flow structure. The grain is vertical with course N. 45° E., parallel to the jointing. The north-south pegmatite dike, up to 4 inches thick, dips 20° S.; the other is vertical and an inch thick. They are garnetiferous. Sap 6 inches thick occurs at the top and bottom of sheets, and " shakes " occur along the sheets near headings. (See p. 40.) Knots, both dark and white, occur but rarely.

The plant consists of 10 derricks, 3 hoisting engines, and 3 steam drills.

Transportation is effected by cartage one-fourth mile to a siding of Somerset Railroad.

The product is used mainly for buildings. Specimen buildings: The post-office at Muskegon, Mich.; the Merrill Library at Norwood, Mass.; the Catholic Church at Lewiston, Me., and the court-house at Bangor, Me. Contract in 1905: Annex to insane asylum at Augusta, Me.

The Lawton quarry is in the town of Norridgewock, on the northwest side of Dodlin Hill and 2½ miles south-southwest of Norridgewock. Operator, F. S. Lawton, Norridgewock.

The rock is a quartz monzonite of medium-gray and light-gray shade and medium and porphyritic texture, identical with that of the Dodlin quarry just described.

The quarry, opened before 1845, consists of two openings measuring 200 by 100 and 300 by 200 feet by from 5 to 10 feet in depth. The loam stripping does not exceed 3 feet.

Rock structure: The same flow structure occurs as at Dodlin quarry, on the other side of the hill. The sheets, up to 5 feet thick, average from 3 to 4 feet and roll over the hill with a dip of 10° both north and south. Between some of the ordinary sheets there are unusual ones, one-half inch in thickness, which in large slabs are flexible. Whether this was in part due to incipient disintegration was not determined. The lenticular form of the sheets gives them the appearance of being very irregular in thickness. Vertical joints, striking N. 60°–65° E., recur at intervals of 10 to 50 feet. The rift is horizontal and grain vertical, with course N. 60° E. Knots, both light and dark, are rare. Sap occurs along the sheets up to 6 inches in thickness. There is a 6-inch dike of white aplite striking N. 80° W., glaciated with the granite at the surface (specimen 116½, *c*).

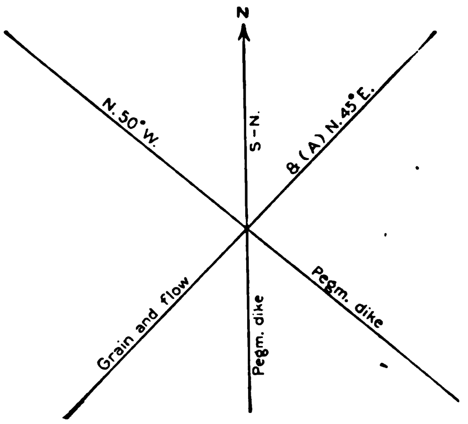

FIG. 33.—General structure at the Dodlin quarry, near Norridgewock.

The plant consists of 3 hand derricks.

Transportation involves a cartage of 3 miles to railroad at Norridgewock.

The product is used for buildings, bridges, and monuments to sup-

ply local demands. Contract in 1905: The town bridge at Bingham, Me.

The Emmons Taylor quarry is in the town of Norridgewock, on Dodlin Hill, about one-fourth mile north of Lawton quarry. Operator, Emmons Taylor, Norridgewock.

The granite (specimen 117, *a*) is a biotite-muscovite granite of light-gray color and very fine even-grained texture. The particles range from 0.11 to 1.1 mm., exceptionally 2.19 mm., and average about 0.50 mm. They consist, in descending order of abundance, of a slightly bluish milk-white potash feldspar (microcline and orthoclase), clear quartz, soda-lime feldspar (oligoclase), black mica (biotite), and very little white mica (muscovite), together with accessory magnetite and apatite.

This is a very small opening, from which stone is obtained occasionally for monumental purposes.

WALDO COUNTY.

The quarries in Waldo County are in the towns of Frankfort, Lincoln, Searsport, and Swanville.

The Mosquito Mountain quarry is in the town of Frankfort, on top of Mosquito Mountain, 2 miles S. 10° E. of Frankfort village. This mountain is a granite dome rising 545 feet above tide water, close by, with a steep east face shown in Pl. III, *B*. Operator, Hayward Peirce, Frankfort, Me.

The granite (specimen 52, *a*) is a hornblende-biotite granite of general medium-gray shade and of porphyritic texture, with milk-white feldspar crystals from one-half inch to 1½ inches in diameter in a gray matrix of medium texture, with black minerals up to one-tenth inch. It consists, in descending order of abundance, of milk-white potash feldspar (orthoclase and microcline), smoky quartz, a milk-white soda-lime feldspar (oligoclase), black hornblende, and black mica (biotite), together with accessory titanite, magnetite, apatite, and a little secondary chlorite, epidote, and carbonate (calcite or dolomite). The porphyritic feldspars are generally twins. Mr. E. C. Sullivan, of the United States Geological Survey, finds that this granite contains 0.1 per cent of CO_2 (carbon dioxide) and that warm dilute acetic acid extracts 0.07 per cent of CaO (lime) and a trace of MgO (magnesia). Figuring the CO_2 to both CaO and MgO, this would give 0.13 per cent of $CaCO_3$ (lime carbonate) and 0.08 per cent of $MgCO_3$ (magnesium carbonate). The microscopic examination corroborates the occurrence of carbonate.

A test of the compressive strength made of this granite in connection with its use for the United States dry docks at Kittery, Me., reported to the writer by Mr. Hayward Peirce, the owner of the

quarry, gives it an ultimate crushing strength of 32,635 pounds per square inch.

The quarry was opened before 1837 on the east side of the mountain. The later opening on the top measures 1,000 feet by 500, with a depth ranging up to 25 feet. There is no drainage problem nor stripping.

Rock structure: The sheets, from 6 inches to 15 feet thick, dip gently northwest and east from the summit of the dome, and below, on the east side, they dip 45°, as shown in Pl. III, *B*. Some of the upper sheets taper out at the sides. (See, further, p. 34.) Vertical joint courses and dike courses are shown in fig. 34. The rift is horizontal and the grain vertical, with course N. 80°–85° W. Some of the joint surfaces are coated with chlorite and pyrite of secondary origin. A dike of quartz monzonite, 10 feet thick, dips 40° E.

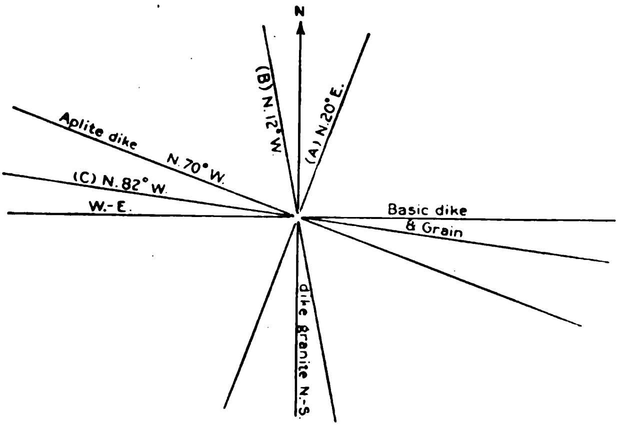

FIG. 34.—Structure at the Mosquito Mountain quarry, Frankfort.

This is described on page 48. There are branching dikes of aplite from 1 to 3 feet thick. At the south end of the quarry is a diabase dike 7 feet thick, crossing from east to west. This is described more fully on page 48. Somewhat abundant knots up to 12 inches in diameter and of circular or elliptical cross section occur. Sap measures up to 12 inches in thickness in the upper sheets, but is absent lower down.

The plant consists of 7 derricks and 3 engines, 1 traveling steam crane, 1 compressor (with capacity of 640 cubic feet of air per minute), 2 steam drills, 10 pneumatic plug drills, 3 surfacers, and 25 pneumatic hand tools.

Transportation is effected by about 7,000 feet of track, and gravity cars from quarry to cutting shed and wharf on Marsh River (South Branch stream), which admits schooners of 14 feet draft.

The product is used for bridge work, and the small sheets and waste go into paving blocks. The chief markets are New York and Philadelphia. Specimen structures: The post-office at Lynn, Mass., and part of that at Chicago, Ill.; the New York Central Railroad bridge across Harlem River. Contracts in 1905: The Manhattan anchorage of one of the new New York suspension bridges.

The Mount Waldo quarry is in the town of Frankfort, on the north spur of Mount Waldo, 660 feet above sea level, one-third mile southwest of Frankfort village. The geographical relations of Mosquito Mountain and Mount Waldo to the Penobscot River are shown on the Bucksport sheet of the United States Geological Survey's topographic map of the United States, published in 1902. This quarry is operated by the Mount Waldo Granite Works, Albert Peirce, treasurer, Frankfort, Me.

The granite (specimen 53, *a*) is a biotite granite of medium-gray shade and fine even-grained texture, with feldspar up to one-fifth inch and biotite scales up to one-tenth inch. The finer particles range from 0.36 to 1.46 millimeters in diameter It consists, in descending order of abundance, of gray potash feldspar (orthoclase and microcline), smoky quartz, gray soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite, titanite, and secondary chlorite. The oligoclase is partly altered to kaolin and a white mica. A coarser and lighter granite (specimen 53, *b*) from the same quarry is a biotite granite of light-gray shade and medium (inclining to fine) even-grained texture, with feldspars up to three-tenths inch, and biotite scales up to one-tenth inch, consisting, in descending order of abundance, of white potash feldspar (orthoclase and microcline), smoky quartz, white soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite, titanite, and secondary chlorite. The oligoclase is partially altered to kaolin and a white mica. This variety is in places coarsely porphyritic. Dr. George P. Merrill refers to the two Mount Waldo granites.[a] A test of the compressive strength of Mount Waldo granite, made at the United States arsenal at Watertown, Mass., in 1900, yielded the following results with 2-inch cubes:[b]

[a] Collection of building and ornamental stones in the United States National Museum: Ann. Rept. Smithsonian Inst., 1889, pt. 2, p. 415.

[b] Kelly, J. W., Ordnance Rept., Tests of Metals, etc. (1900), 1901, p. 119.

Test of Mount Waldo granite.

Number of test.	Direction of pressure.	Specific gravity.	First crack.	Total pressure applied.	Ultimate strength per square inch.
			Pounds.	*Pounds.*	*Pounds.*
11055	At 90° to rift	2.637	120,000	128,400	31,782
11056	do	2.655	123,300	132,500	32,635
11057	Parallel to rift	2.662	107,400	122,600	30,197
11058	do	2.649	112,600	117,900	29,183

The quarry, opened before 1851, measures 800 feet from north to south by 400 feet from east to west and from 10 to 30 feet in depth. There is no drainage problem nor stripping.

Rock structure: There is a vertical dike of the coarser and lighter granite (specimen 53, *b*) 200 feet or more wide, having a course N. 20° W., with the darker granite (specimen 53, *a*) on both sides of it, the relations indicating vertical flow structure. The longer axes of

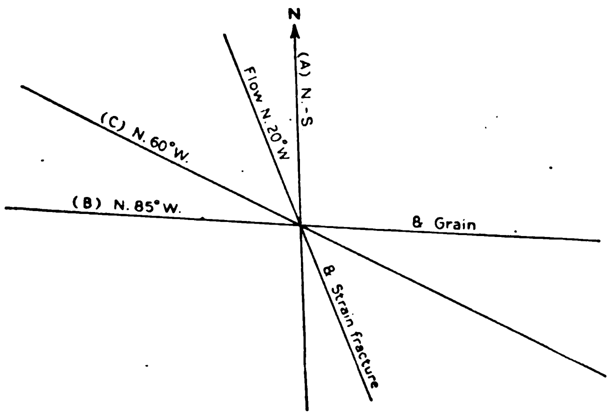

FIG. 35.—Structure at the Mount Waldo quarry, Frankfort.

many of the feldspars lie about north-south. The sheets, from 8 inches to 8 feet thick and lenticular, dip 10° E. The joint courses are shown in fig. 35. There is only one joint of A. Joint B recurs at intervals of 40 feet; C at intervals of 20 to 40 feet or more. The rift is horizontal and the grain vertical, trending N. 85° W. The granite is under compressive strain from east-northeast to west-southwest, causing north-northwest to south-southeast vertical fissures the entire length of the quarry. This fissuring has occurred in summer time and has been accompanied by an explosive noise. The sheets are very free from sap. Knots are exceptional, but one near the junction of the fine and medium granites measures 6 feet by 3 feet and consists of a medium gray aplite, with porphyritic whitish twinned feldspars up to three-fourths inch in length and biotite scales up to one-twentieth inch.

The plant consists of 10 derricks, 6 hoisting engines, 1 traveling crane, 1 locomotive crane, 2 compressors (capacity 925 and 500 cubic feet of air per minute), 6 steam drills, 1 channeler, 12 pneumatic plug drills, 10 surfacers, 60 pneumatic hand tools, and 1 steam pump.

Transportation is effected by two graded tracks, each 1,200 feet long, operated by gravity from the quarry part way down the hill to the power house, thence by a cable road (Roebling engine) 1¼ miles long, to the wharf, which is accessible to schooners of 15-feet draft. Heretofore the stone destined for the West has had to be transferred to cars at Bucksport, on Penobscot River, 7 miles distant, but the new Northern Maine Seaport Railroad, a branch of the Bangor and Aroostook, which passes at the foot of the hill, will obviate this reshipment.

Some of the stone quarried at the Mosquito Mountain quarry is finished here.

The product is used for buildings, and has of late found its chief market in the West. The small sheets and waste are made into paving blocks. Specimen buildings: Milwaukee and Indianapolis post-offices, Philadelphia mint. Contract in 1905: Cleveland, Ohio, post-office.

The Fernald quarry is in the town of Lincoln, near the north end of Lake Megunticook. Operator, E. H. Fernald Granite Company; address, Lincolnville R. F. D.

The granite (specimen 50, *a*) is a muscovite-biotite granite of light-gray shade and fine (inclining to medium) even-grained texture, with feldspars up to 0.2, muscovite to 0.15, and biotite up to 0.1 inch. The finer particles range from 0.18 to 1.83 mm. in diameter. The rock consists, in descending order of abundance, of slightly bluish-white potash feldspar (orthoclase and microcline), smoky quartz, whitish soda-lime feldspar (oligoclase), white mica (muscovite), and still less of black mica (biotite), together with accessory apatite. The oligoclase is much altered to kaolin. The feldspars generally are intergrown with quartz in particles that are circular in cross section. The stone takes a fair polish with a bluish tinge, although the size of the muscovite plates is against the great durability of the polish under outdoor exposure.

The quarry, opened about 1875, measures 100 by 50 feet, and has a maximum depth of 28 feet. Drainage is effected by pumping on the average half a day per week. The water thus obtained supplies the boiler. The stripping in places measures up to 6 feet.

Rock structure: The sheets, from 6 to 15 feet thick, dip 25° S. Vertical joints, striking N. 60° 65° W., recur at intervals of 8, 14, and 23 feet; also a joint striking N. 60° 65° E., but not recurring. Another one strikes N. 60° W., and dips 60° SE. The rift is verti-

cal, with course N. 60°–65° W. Sap is faint, and from 4 to 8 inches thick along the sheets. Knots, up to 8 by one-half inch, are rare.

The plant consists of 5 derricks, 1 hoisting engine, 1 steam drill, and 2 pumps.

Transportation is by cartage 5 miles to electric railroad, then 8 miles to Maine Central Railroad. The quarry is 50 feet above Megunticook Lake, and a gravity track could be laid one-third mile to the lake, where boats could bring the stone within 2½ miles of Camden, on Penobscot Bay, thus reducing the cartage, which at present is the chief obstacle.

The product is used for monuments and buildings to supply local demands. Specimen buildings and monuments: The trimmings to Carlton Block, in Rockport, Me.

The Heal black-granite quarry is in the town of Lincoln, about 2 miles from bridge over outlet to Tilden Pond, and about 3½ miles from shore of Penobscot Bay. Operator, A. S. Heal, of Heal & Wood; office, Bridge street, Belfast, Me.

This rock is an olivine norite of black shade, with glistening surfaces and of medium texture. The polished surfaces show a brilliant dark olive-greenish mineral. Under the microscope this rock consists of interlacing slender crystals of a translucent lime-soda feldspar (labradorite, with 10 to 14 per cent of lime), the spaces between which have been filled with the following minerals, in descending order of abundance: Greenish hypersthene (see p. 57), black hornblende, greenish olivine, black mica (biotite), and magnetite, with accessory pyrite and secondary chlorite and serpentine. The stone takes a brilliant polish and under sunlight shows the greenish hypersthene. The hammered or cut surface is very light.

The quarry, opened in 1903, measures 30 by 40 feet and about 10 feet in depth. It is worked only occasionally. There is no machinery. The stone is now carted 7 miles to Belfast to be cut. It is used for dies and tablets for local demand and is admirably adapted for these purposes.

The Bog Hill quarry is in the town of Searsport, on Mount Ephraim (Bog Hill), about 5 miles north-northwest of Searsport village and 2 miles east of Swanville. Operator, Herbert Black, North Searsport.

The granite (specimen 51, *a*) is a biotite granite of light-gray shade and porphyritic texture, with feldspars up to 1½ inches in diameter, in a groundmass of medium texture, with biotite scales up to one-fifth inch. It consists, in descending order of abundance, of a whitish potash feldspar (orthoclase and microcline), smoky quartz, whitish soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite, titanite, zircon, apatite, and secondary chlorite and epidote. The porphyritic orthoclase crystals,

generally twinned, are intergrown with oligoclase and quartz. Some have a zonal structure indicated by inclusions of quartz and oligoclase. The oligoclase is partially altered to kaolin and a white mica.

The quarry is 200 feet from north to south by 50 feet from east to west, and averages about 5 feet in depth.

Rock structure: The sheets, from 1 to 4 feet thick, dip 10° S. 30° E., and are crossed by joints that strike N. 75° W. and dip 65° N. and 65° S., forming headings at the south side and one in the center. Black knots up to 2 inches across occur here and there; also pyrite crystals on the joint faces.

This stone has been used for monuments and buildings in Belfast and for paving blocks, but the quarry has not been in operation for five years. The product had to be carted 5 miles to Searsport.

The Oak Hill quarry is in the town of Swanville, on Oak Hill, about 6 miles north-northwest of Belfast. Operator, Oak Hill Granite Company, Belfast, Me.

The granite (specimen 49, *a*) is a biotite granite of slightly bluish dark-gray color and fine even-grained texture, with particles ranging generally from 0.25 to 1 mm. in diameter and an occasional feldspar up to 2.5 mm. or one-tenth inch. It consists, in descending order of abundance, of slightly bluish-white potash feldspar (microcline and orthoclase), smoky quartz, slightly bluish-white soda-lime feldspar (oligoclase), and black mica (biotite). The feldspars are intergrown with quartz and the oligoclase is here and there partially altered to a white mica. The stone takes a very fine polish to the durability of which the fineness of the mica contributes.

The quarry, which was opened about 1872, consists of several openings, the largest of which is 175 by 100 feet, with a working face 60 feet high.

Rock structure: The sheets, from 1 to 4 feet thick, dip 10° W. Vertical or steep joints, striking N. 80° W., recur at intervals of 10 and 20 feet, and form headings on the north side. Sap 2 inches thick occurs along the sheets. Knots up to 2 inches in diameter occur occasionally.

There is no machinery at the quarry at present. The only work being done is the making of paving blocks at one of the openings.

Transportation was by cartage one-fourth mile to a siding running from Sargents Crossing on the Maine Central Railroad.

The product is particularly adapted to monumental uses. The stone is the darkest of the fine-textured granites of the State (compare Freeport, p. 77; Pownal, p. 79; and Sherwood, p. 105) and is finer textured than the blue Westerly, R. I., granite. This quarry was formerly leased to the New England Granite Company, of Westerly.

WASHINGTON COUNTY.

The quarries in Washington County are in the towns of Addison, Baileyville, Calais, Jonesboro, Jonesport, Marshfield, and Millbridge.

The Pleasant River black-granite quarry is in the town of Addison, at Dalotville, on the east side of Pleasant River Bay. Operator, Pleasant River Granite Company, Addison, Me.

This rock (specimen 93, *a*) is an hypersthene-olivine gabbro of almost black shade and of medium ophitic texture, with black particles up to half an inch and slender whitish crystals. The polished surface is jet-black mottled with a little white. Under the microscope this rock consists, in descending order of abundance, of slender whitish transparent crystals of a feldspar (with both lime and soda, andesine-labradorite) intricately interlaced, the spaces between which are filled with a dark-brownish diallage (see p. 57), black mica (biotite), a little hypersthene, and greenish olivine, together with secondary magnetite, a white mica, and calcite. The diallage is altered along its edges to hornblende. The stone takes a very fine polish, and the hammered or cut surface is almost white. It is referred to by George P. Merrill[a] and by John E. Wolff.[b] It was reported to the company by John S. Newberry in October, 1890, as withstanding a pressure of 22,410 pounds per square inch. Its weight is given by the firm as 184 pounds to the cubic foot.[c]

The quarry, opened about 1885, measures 75 by 50 feet and has a working face about 50 feet high. It is on the south side of a ridge 70 feet high, extending east-west, the upper 5 to 10 feet of which consist of morainal sand and bowlders. (See Pl. X, *A*.)

Rock structure: The sheets, from 3 to 17 feet thick, undulate from the horizontal to a dip of 10° E. Vertical joints, striking N. 80° E., recur at intervals of 5 to 10 feet and form a heading on the south; a set, striking N. 35° W., recurs at intervals of 20 to 30 feet, forming a heading on the west. There are also several irregular fractures. The rift is vertical east-west, and the grain is horizontal. There are 10 feet of stained and fractured rock at the top, but sap is usually hardly an inch in thickness. Dikes of whitish quartz monzonite, described in detail on page 61, measure from 1 to 14 inches in thickness. There is also a more or less horizontal light and dark banding, due to alternating changes in the amount of feldspar. This is shown in Pl. X, *A*, as are also the dikes, sheets, joints, and one of the headings.

The plant consists of 3 derricks and 2 hoisting engines, 1 steam drill, 1 compressor, 2 pneumatic hand tools, 2 polishers, 1 polishing

[a] Tenth Census, vol. 10, 1884, p. 24.

[b] Ibid., p. 116.

[c] Professor Newberry's report will be found in the Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 5, continued, 1897, p. 961.

lathe for stones 12 by 4 feet, 1 gang of steam saws, and 1 single steam saw for use with steel shot.

Transportation is effected by cartage on a track 300 feet from quarry to mill and 300 feet thence to wharf on Pleasant River Bay.

The product is used for monuments and interior decorations and finds market in the cemeteries of Brooklyn, Boston, Chicago, Louisville, Denver, and other cities. As will be noticed from the spacing of the joints and sheets, the dimensions of the blocks are limited. The usual sizes shipped measure 2 feet 6 inches by 2 feet 6 inches by 1 foot and also 3 to 6 feet by 1 foot by 1 foot. The largest block shipped measured 6 feet by 4 feet 6 inches by 4 feet 6 inches. During the writer's visit in August, 1905, the men were endeavoring to quarry a block which measured 17 feet by 9 feet, the third dimension of which was still uncertain.

Specimen work: Base of wainscoting in the city hall at Philadelphia; tablet with Welsh incription in Washington Monument at Washington, D. C.; Danforth monument at Morristown, N. J.; Zeller monument at Lewisburg, Pa.; center monument at Greenwood Cemetery, Brooklyn, N. Y.; and mantlepiece in public library at Machias, Me. Contract in 1905, memorial to Architect French in New York.

The Thornberg black granite quarry is in the town of Addison, 3 miles south of Addison village. Operator, A. M. Thornberg, Addison, Me.

The rock (specimens 94, *a* and 94, *aa*) is a hypersthene-gabbro of almost black shade and of medium ophitic texture. There are two varieties—a dark one, which is externally identical with that examined from the Pleasant River quarry, and a lighter one, in which the white mottling due to the feldspar is a little more abundant. Under the microscope this stone is generally identical with that of the Pleasant River quarry, except that in the thin section of this one the feldspar is labradorite and there is no olivine. This, however, may not be characteristic of the rock as a whole. A little accessory pyrite and apatite and a good-sized particle of secondary epidote were also found in the Thornberg gabbro. The stone takes a very fine polish and the hammered or cut surfaces are almost white.

The Black Diamond Granite quarry is in the town of Addison, on Yoho Bay. Owned by Black Diamond Granite Company of New York; address, Basin, Me., or care H. Donald, tax collector, Addison, Me.

The rock (specimen 91, *a*) is a hypersthene gabbro of very dark-gray shade, with slight brownish tinge and of fine to medium ophitic texture, consisting, in descending order of abundance, of a whitish soda-lime feldspar (andesine) in not greatly elongated crystals,

brownish diallage (partially altered to hornblende), black mica (biotite), a little hypersthene, and quartz, together with accessory magnetite. This rock turns a little brownish on continued exposure and weathers spheroidally. A polished block, reported as from this quarry and shown to the writer in a stonecutter's yard at Quincy, Mass., had become pitted from exposure.

The quarry, opened in 1883 and abandoned in 1902, is 200 feet square and from 10 to 20 feet deep. It has a track 300 feet long to a wharf which admits schooners of 11 feet draft. Although the rock has been here worked down to sea level, there is, a few hundred feet east, on the property of William N. Carver, a rising ridge of the same rock which is as yet untouched.

Rock structure and variations: The sheets, from 3 to 8 feet thick, are horizontal or dip 20° N. Vertical joints, striking N. 80° E., recur at intervals of 5 to 20 feet, and a set, striking N. 30° W., recurs at intervals of 2 to 10 feet. There is rarely a set striking N. 45°–50° W. A 1-inch dike of pegmatite strikes N. 30° W.

The Hall black-granite quarry is in the town of Baileyville, at the north edge of Meddybemps Lake, 5 miles southwest of Baring, on Washington County Railroad, about 7 miles southwest of Calais. Operator, F. H. Hall, Calais, Me.

The rock (specimens 98, *b*, *d*) is a norite of brilliant luster, very dark gray shade (without any yellowish tinge), and of coarse texture and marked rift, with jet-black particles up to one-half inch in diameter in a network of translucent whitish feldspar. Under the microscope it consists, in descending order of abundance, of elongated transparent crystals of feldspars (with both soda and lime, andesine-labradorite) interlaced, but parallel in the flow and rift direction, with the intervening spaces filled with hypersthene (partially altered to brown hornblende), magnetite, and black mica (biotite), together with accessory calcite and a white mica derived from the partial alteration of a few of the feldspars. The hypersthene and hornblende constitute the conspicuous black particles seen with the unaided eye. In the lighter bands of the rock the feldspar largely crowds out the hypersthene. The content of magnetite is so great that large blocks of the rock deflect the magnetic needle. Mr. Hall states that the stone endures the fire and water test very well; that its compressive strength, as determined by the Watertown Arsenal testing machine, is 22,500 pounds to the square inch, and that an assay by Carmichael, of Boston, shows it to contain a small percentage of gold. The papers giving formal evidence of these results having, unfortunately, been misplaced, can not be cited here. The stone takes a high polish and the hammered and cut surface is almost white. It is very tough, but splits with facility along the rift.

The quarry, opened in 1902, consists of two adjacent openings on the northeast side of a northwest-southeast ridge over one-fourth mile long and about 50 feet high. These openings measure 60 by 25 feet and 35 feet in depth and 50 by 20 feet and 20 feet in depth, respectively.

Rock structure: The upper 8 feet of the working face are traversed by light-gray more feldspathic bands from one-fourth to 2 inches in thickness, constituting a flow structure parallel to the sheets, which are from 1 to 6 feet thick and dip about 15° SW. Vertical joints, striking northeast-southwest, cross the ridge at intervals from 6 inches to 7 feet, and form a heading in the smaller northwesterly opening. The rift is parallel to the sheets. As will be noticed by comparing the descriptions of the rock structure at the other black-granite quarries, the structure along this ridge is unusually favorable for quarrying.

The plant consists of 1 power and 1 hand derrick and 1 engine and 1 steam drill.

Transportation is effected by cartage of 5 miles to Baring on the Washington County Railroad.

The quarry was not in operation in 1905.

The product is used for tablets and monuments, and has found a market in New York, Boston, Philadelphia, Baltimore, Virginia, Nebraska, Dakota, and California.

Specimen monuments: A monument erected by Stephen A. Lovejoy, of Melrose, Mass., at Melrose Cemetery; also several monuments at the cemetery in Calais, Me.

The Tarbox black-granite quarry is in the town of Baileyville, about 900 feet northeast of the Hall quarry described above, at the north edge of Meddybemps Lake, 5 miles southwest of Baring, on the Washington County Railroad, and about 7 miles southwest of Calais. Lessee, O. S. Tarbox, Redbeach, Me.; owner of mineral right, F. H. Hall, Calais.

This rock is a norite identical with that of the Hall quarry described above. It appears to belong to an outcrop northeast and parallel to the ridge referred to.

The plant consists of 1 derrick.

Gardner's black-granite prospect is in the town of Calais, on St. Croix River, 6 miles south of Calais, north of road to Redbeach. Owner, Lorenzo Gardner, Calais, Me.

This rock (specimen 100, *a*) is a quartz diorite of very dark gray (not bluish) shade and fine, even-grained texture, consisting, in descending order of abundance, of a whitish soda-lime feldspar (andesine) considerably altered to a white mica, hornblende partly altered to chlorite, quartz, black mica (biotite), and magnetite, together with accessory titanite, pyrite, apatite, and secondary cal-

cite. It takes a high polish, and the hammered and cut surfaces are very light. The stone is suitable for monumental work. Dr. George Otis Smith, who visited the Gardner prospects in 1903, states that "pink granite occurs intrusive in the dioritic rock in such a manner that both kinds of stone could be quarried from the same opening." One part of the dioritic rock he found in thin section to be in reality a diabase.

Mingo, Bailey & Company's black-granite quarry is in the town of Calais, about 6 miles south of Calais, on the southwest side of the road to Redbeach, on the north side of an east-west ridge, near top. Operator, Mingo, Bailey & Co.; office, Redbeach, Me.

The rock (specimen 103, *a*) is a norite, of almost black with slightly greenish tinge and fine to medium even-grained ophitic texture, consisting, in descending order of abundance, of a whitish soda-lime feldspar (andesine) considerably altered to a white mica, hypersthene (some of it partially or entirely altered to fibrous actinolite), magnetite, and black mica (biotite), with accessory pyrite. The stone takes a fine polish and affords a very light hammered or cut surface.

The quarry measures 50 by 15 feet and up to 20 feet in depth. The sheets are about 10 feet thick. Vertical joints, striking about east to west, recur at intervals of 1 to 3 feet.

There is one derrick. The quarry is worked only occasionally, and the stones are carted to the company's cutting shed, near Redbeach, on the St. Croix River.

The Beaver Lake black-granite quarry is in the town of Calais, near the north end of Beaver Lake, 4 miles west of Redbeach village. Operator, Maine Red Granite Company; office, Redbeach, Me.

The rock (specimen 96, *g*) is a mica-quartz diorite of general dark-gray shade (black mottled with white and gray) and of coarse to medium porphyritic texture, with feldspars up to one-half inch in diameter. It consists, in descending order of abundance, of a grayish feldspar containing both soda and lime (andesine-labradorite), black hornblende, black mica (biotite), magnetite, and a little quartz, together with accessory pyrite, calcite, and apatite. The feldspar is partly altered to kaolin and a white mica, producing the milky-white parts of the feldspars seen in the polished specimen, and some of the hornblende is fibrous. The stone takes a high polish and when hammered or cut has a very light surface.

The quarry, opened in 1885, measures 250 feet from north-northeast to south-southwest by 75 feet across, and has a working face on the east 30 feet in height. Its drainage requires the use of pumps in spring.

Rock structure: The sheets, from 6 inches to 7 feet 6 inches thick, dip 15° W., and are lenticular in form. The upper 10 feet of the face

consist of shattered surface rock and include a bed a foot thick of sand, due to interstitial weathering. The courses of joints and dikes are shown in fig. 36. A recurs at intervals of 2 to 10 feet, B at intervals of 10 feet, C still less frequently. There are also irregular joints, which break the rock up into irregular blocks.

A dike of pinkish aplite, described on page 61, from 4 to 8 feet thick, runs the entire length of the quarry on the west. A 1-inch dike of white aplite dips 15° S. Similar ones recur at frequent intervals. Some strike northward and curve. A dike of olivine basalt, referred to on page 61, occurs also on the west side or front of the quarry, and is crossed by branches from the large pinkish aplite dike. The rift is horizontal and the grain vertical, trending north-northeast to south-southwest. Thus, altogether, the structure and injections are complex and render the quarrying of large blocks difficult. Notwithstanding this, blocks 9 by 9 feet by 20 inches have been obtained, and one 12 by 12 by 6 feet was in sight in 1905.

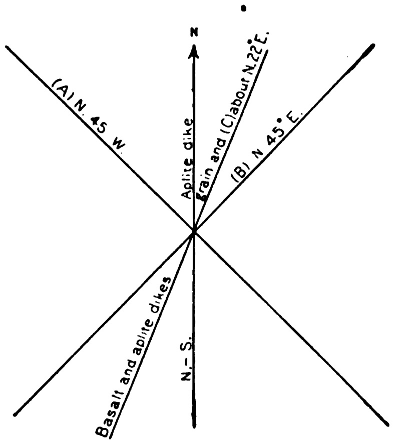

FIG. 36.—Structure at the Beaver Lake diorite quarry, Calais.

The plant consists of a derrick, engine, and pump.

Transportation involves cartage of 4 miles to the company's cutting mill at Redbeach and a further cartage of one-fourth mile to wharf on St. Croix River.

The product is used entirely for monuments, of which the soldiers' monument at Calais is a specimen.

The Shattuck Mountain quarry is in the town of Calais, 3 miles west-southwest of Redbeach village, on Shattuck Mountain. Operator, Maine Red Granite Company; office at Redbeach, Me.

The granite (specimen 104, *b*) is a biotite granite of dark reddish-greenish gray color and medium to coarse even-grained texture, with feldspars up to one-half inch and sparsely disseminated biotite under one-tenth inch. It consists, in descending order of abundance, of a reddish potash feldspar (orthoclase), smoky quartz, greenish soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite, apatite, and secondary chlorite. The oligoclase is here and there partially altered to a white mica. The smallness and sparseness of the micas are favorable to the durability of its polish.

The quarry, opened in 1890, consists of three openings on the south side of an east to west ridge. The principal one of these measures

50 by 25 feet and from 10 to 20 feet in depth. The sheets, from 5 to 7 feet thick, are horizontal or dip south at a small angle. Joints, striking N. 25° E. and dipping 70° NNW., recur at intervals of 10 to 22 feet and form headings on the north and south sides of the quarry. Another set, striking N. 40° W., dips 65° W., forms a heading on the east side and recurs in middle of quarry. The 22-foot column referred to under " product " came from a 6 foot 6 inch sheet between the first set of joints. The heading of that set on the north is about 6 feet thick and includes a bed of clayey sand 8 inches thick. It has three sets of subjoints, one striking N. 40° E. and dipping 55° SE., spaced 2 to 12 inches; another striking N. 50° W., vertical, and spaced 6 inches to 2 feet, and another striking N. 60° E., vertical, and spaced 4 to 12 inches. The rock has no rift. The weathering of this granite has been referred to on page 55.

The plant consists of a derrick.

Transportation is by cartage of 3 miles to Redbeach, on the St. Croix River.

The product is used for ornamental and monumental work. Specimens: Four fluted columns 22 feet by 3 feet, for the court-house at Marquette, Mich.

Mingo, Bailey & Company's red-granite quarry is in the town of Calais, 1½ miles north-northwest of Redbeach. Operator, Mingo, Bailey & Co., Redbeach, Me.

The granite (specimen 102, *b*) is a biotite granite of dark-reddish color speckled with pale greenish and of medium even-grained texture, with feldspars up to two-fifths inch and sparse biotite under one-tenth inch. It consists, in descending order of abundance, of a dark-pinkish potash feldspar (orthoclase), very smoky quartz, a pale yellowish-greenish soda-lime feldspar (oligoclase) considerably altered to a white mica, black mica (biotite), and accessory magnetite and zircon. The rock takes a high polish that exhibits marked contrasts between the two feldspars and the smoky quartz. The smallness and sparseness of the biotite scales favor the durability of the polish. The stone is of a lighter red than that of the Shattuck Mountain quarry, but is darker than that of the Maine Red Granite Company's " old quarry."

The quarry is 25 feet square by 8 feet deep, and is without machinery.

The company has at its cutting shed 1 derrick, 1 engine, and 1 polisher.

Transportation is had by cartage 1½ miles to wharf at Redbeach.

The product is used entirely for monuments.

The Maine Red Granite Company's red-granite quarry is in the town of Calais, three-fourths mile west of Redbeach. Operator, Maine Red Granite Company; office, Redbeach, Me.

The granite (specimen 97, *a*) is a biotite granite of general bright pinkish color and medium even-grained texture, with feldspars up to two-fifths inch and sparse biotite scales under one-tenth inch. It consists, in descending order of abundance, of a pinkish potash feldspar (orthoclase), smoky quartz, cream-colored soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite and zircon. The oligoclase is partially altered to kaolin and a white mica. The stone takes a high polish, the durability of which is favored by the sparseness and smallness of the mica scales. In weathering about the quarries the feldspars whiten from increasing kaolinization. The contrasts are chiefly between the two feldspars and the smoky quartz. This type of "red granite" is the brightest of those occurring in Maine.

The quarry consists of two openings, one known as the "old quarry," opened in 1876, and a new one adjacent to it. The new one is about 150 feet square by 20 to 50 feet deep.

Rock structure: The sheets, from 6 inches to 5 feet thick, dip 10°–30° SE. Joints, striking N. 80° W. and dipping steep to the north, recur at intervals of 1 to 5 feet. Others, striking N. 40° E. and dipping 80° SE., recur at intervals of 6 inches to 5 feet. The faces of this set are coated with calcite and epidote. There is no rift whatever. It is evident from the frequent recurrence of both sets of joints and the limited range in thickness of the sheets that the conditions are not favorable for quarrying large blocks. Prof. John E. Wolff refers to the structure of Redbeach granite.[a]

The plant consists of a derrick.

Transportation involves cartage of three-fourths mile to wharf on St. Croix River.

The product is used entirely for monumental and ornamental work and finds a market all over the United States.

The Maine Red Granite Company's granite works are in the town of Calais, one-fourth mile west of Redbeach.

The red-granite quarries operated by this company at Shattuck Mountain, near Redbeach, have already been described and also its black-granite quarry at Beaver Lake.

This company not only finishes the product of its own quarries, but has the most extensive plant for polishing granite in the State and receives granite for finishing from the Stonington, Mount Desert, and North Jay quarries. It makes a specialty of columns, panels, and wainscoting.

The plant is run partly by water power obtained from a stream flowing into the St. Croix River and partly by an auxiliary 150-horsepower engine. It includes 1 derrick and 3 hoisting engines, 1 steam crane (with a capacity of 25 tons), 4 cutting lathes (for stones of

[a] Tenth Census, vol. 10, 1888, p. 116.

25 by 4, 15 by 2½, and 10 by 1½ feet), 4 polishing lathes for smaller stones, 7 " Jenny Lind " polishers, 2 vertical polishers for small work, 2 pendulum polishers, 1 saw (for use with steel shot) with 2 blades, 23 feet long, and a Donald cutting machine for smaller stones, 20 by 6 feet.

Specimens of polished work done by this company: Four fluted columns (22 by 3 feet) of Shattuck Mountain red granite for the court-house at Marquette, Mich.; balusters of gray granite (Goss Crotch Island quarry) for Kansas City court-house; vault of gray granite for Marinoni grave at cemetery in New Orleans, La. The soldiers' monument, of Beaver Lake black granite, at Calais, Me., was also finished here.

The Redbeach Granite Company's quarry is in the town of Calais, on Cooks Mountain, 8 miles southeast of Calais, about 1,000 feet southwest of road to Redbeach. Operator, O. S. Tarbox, Redbeach, Me.

The granite is a biotite granite of general bright pinkish color and medium even-grained texture like that of the Maine Red Granite Company's quarry near Redbeach, described on page 166, and of the abandoned Bodwell Granite Company's quarry on Cooks Mountain.

The quarry, opened in 1895, is 50 by 25 feet and from 5 to 20 feet deep. The sheets, up to 5 feet thick, dip north at low angle. Vertical joints strike N. 80°–90° E., forming numerous headings. There is no rift.

The plant consists of 1 derrick and 1 hoisting engine.

Transportation involves cartage of over one-half mile to wharf on St. Croix River at Redbeach.

The product is used for buildings and monuments. Specimen structures: The red granite in two corner wings of the American Museum of Natural History, in New York; the pedestal to General Grant's monument, at Galena, Ill.

The Horsebrook Mountain quarry is in the town of Jonesboro, at Quarry siding, about 2 miles east of Jonesboro station, on the Washington County Railroad. This quarry was opened in 1903 by Cyrus F. Stackpole, of Bangor, Me., and furnished a " pink granite " for the Roman Catholic Church, the Commercial block, and the Pierce block, at Oldtown, Me., and the new schoolhouse at Great Works, Me. These facts were submitted by Samuel S. Kimball, of Bangor, to the State Survey Commission. The quarry was not in operation in 1905, and specimens of the stone were not obtainable for description in this report.

The Fish quarry is in the town of Jonesboro, 1 mile northwest of Jonesboro village. Owner, N. W. Fish, Jonesboro, Me.

The granite (specimen 87, *b*) is a biotite granite of lavender medium-gray color and medium, even-grained texture, with feldspars

generally up to two-fifths inch (exceptionally one-half inch) and sparsely disseminated biotite up to one-tenth inch. It consists, in descending order of abundance, of a pale lavender-colored potash-feldspar (orthoclase), smoky quartz, milk-white soda-lime feldspar (oligoclase), and a little black mica (biotite), together with accessory magnetite and secondary epidote, zoisite, and calcite. The feldspars are considerably altered to white micas, and the biotite is also largely altered to chlorite. This stone resembles that of the Goss and Ryan-Parker quarries of Crotch Island in the lavender tint of its orthoclase, but its texture is finer. Their resemblance may be found to be still greater in lower and fresher sheets.

The quarry, a small opening about 300 feet northwest of Mr. Fish's house, has been worked only occasionally. The sheets are up to 5 feet thick and lie horizontal.

The Bodwell-Jonesboro quarry is in the town of Jonesboro, 2 miles east of Jonesboro village. Operator, Bodwell Granite Company; office, Rockland, Me.

The granite (specimen 86, *h*) is a biotite granite of general grayish-pink color and of coarse (inclining to medium), even-grained texture, with biotite sparsely disseminated and up to one-twentieth inch in diameter. It consists, in descending order of abundance, of a pinkish potash feldspar (orthoclase), smoky quartz, cream-colored soda-lime feldspar (oligoclase), and a little black mica (biotite), together with accessory magnetite and secondary white mica, kaolin, and chlorite. The orthoclase is intergrown with plagioclase, and the oligoclase is here and there largely altered to a white mica and kaolin and the biotite to chlorite. The contrasts are chiefly between the two feldspars and the smoky quartz. The stone takes a fine polish, the durability of which is favored by the smallness of the biotite scales.

The quarry, opened about 1875, measures about 700 feet N. 80° E.–S. 80° W. by 200 feet from north to south, and has a depth of 10 to 33 feet. Its area is irregular, as shown in fig. 37. Its drainage requires occasional pumping.

Rock structure: This quarry shows a greater variety of dike courses than any other of the Maine quarries. The sheets, from 6 inches to 5 feet thick, are horizontal, with slight undulations. The joint and dike courses are shown in fig. 37. A recurs on the north and south sides of quarry and in middle, and forms a heading on the south; B forms a heading on the northwest side; C appears on the south wall, intersecting the heading; D dips steep south, and also intersects the south wall. The rift is vertical, with course N. 70° W. There are two dikes of reddish aplite (*a*), one 6 feet thick, another 4 feet thick; a third (*b*), also reddish, is from 3 to 6 feet thick; a grayish aplite dike (*c*), from 1 to 1½ inches thick, can be traced from 200 to 300 feet, cutting all the other dikes. Thin sections of *a* are

described on page 43. Knots occur up to 12 by 8 inches, but rarely. There are geodes and short veins, containing quartz, epidote, and calcite. (See p. 50.) The sheet surfaces are in places coated with epidote from the alteration of feldspar. Prof. John E. Wolff has referred to the Jonesboro "red granite" and some of its peculiarities.[a]

The plant consists of 4 derricks, 2 hoisting engines, 2 steam drills, and 1 steam pump.

Transportation involves cartage of a mile to the wharf on Englishmans Bay. The stone is shipped to Vinalhaven for finishing.

The quarry was not in operation in 1905 for want of demand for "red granite."

The product was used for buildings. Specimen buildings made of granite from this quarry: Custom-house and post-office at Buffalo,

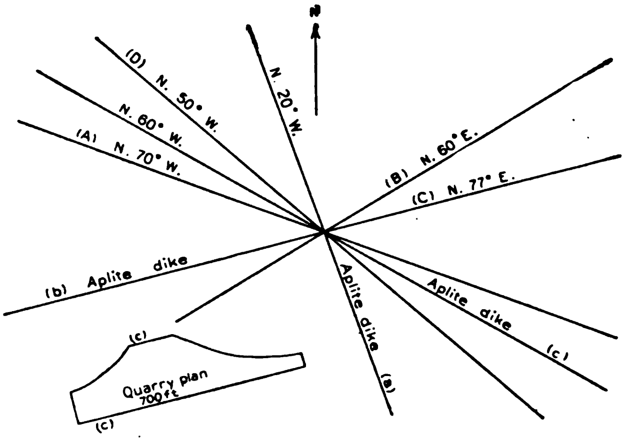

FIG. 37.—General plan and structure at the Bodwell quarry, Jonesboro.

N. Y.; Methodist Book Concern building and Havemeyer residence, Fifth avenue and Sixty-sixth street, New York; custom-house and post-office at Fall River, Mass.; town buildings at Peabody, Mass.; Western Savings Bank building, Philadelphia.

The Booth Brothers Jonesboro quarry, in the town of Jonesboro, is 1¼ miles east of Jonesboro village. Operator, Booth Brothers & Hurricane Isle Granite Company; office, 207 Broadway, New York; Maine office, Rockland, Me.

The granite (specimen 85, *b*) is a biotite granite of general pinkish-gray color and coarse, inclining to medium, even-grained texture, with sparsely disseminated biotite up to one-twentieth inch in diameter. It consists, in descending order of abundance, of a pinkish potash feldspar (orthoclase), a little less pink than that of specimen

[a] Tenth Census, vol. 10, 1888, p. 116.

86, *h*, from the Bodwell quarry, smoky quartz, cream-colored soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite and secondary white micas, zoisite, and chlorite. The orthoclase is here and there intergrown with a plagioclase. The oligoclase is largely altered to a white mica and kaolin and the biotite to chlorite. The contrasts are between the two feldspars and the smoky quartz. The stone takes a high polish, the durability of which is favored by the smallness of the biotite plates. Its general color is not quite so pinkish as that of the Bodwell quarry.

The following chemical analysis of this granite was made by Ricketts & Banks, of New York (No. 16072), and is given here merely for purpose of reference:

Analysis of granite from Jonesboro quarry.

SiO_2 (silica)	72.97
Al_2O_3 (alumina)	14.63
FeO (ferrous oxide)	1.73
CaO (lime)	1.48
MgO (magnesia)	0.27
MnO (manganese oxide)	0.10
Na_2O (soda)	3.28
K_2O (potash)	5.18
S (sulphur)	0.03
CO_2 (carbon dioxide)	None.
Loss and undetermined	0.33
	100.00

The quarry is of triangular area, about 10 by 75 by 75 feet and 30 feet deep. It is or can be drained by siphoning. The stripping consists of 3 to 5 feet of till.

Rock structure: The sheets, from 5 to 10 feet thick and lenticular, lie horizontal or dip 5° NW. or 5° SE. A vertical joint striking N. 60° W. forms the wall on the southwest. A set striking N. 35°–50° E. forms headings on the northwest and southeast and recurs at intervals of 5, 10, 20, and 70 feet. Its faces are coated with hematite. The rift is vertical, with course N. 60° W. The grain is horizontal. Knots are small and infrequent. Sap up to 3 inches thick is confined to the headings. The structural conditions are favorable for quarrying large blocks.

The plant consists of 1 derrick.

Transportation is effected along a track one-third mile to wharf on Englishmans Bay.

The quarry was idle in 1905.

The product is shipped to the company's works on Hurricane Island to be finished and is used for building.

The Minerva Cove quarry is in the town of Jonesport on the north side of Head Harbor Island, which lies about 3½ miles southeast of Jonesport. Operator, Metropolitan Granite Company; office, Jonesport, Me.

The granite (specimens 88, *a*, and 88, *b*) is a biotite granite which in the lower sheets is of general dark reddish-gray color, with both a pinkish and a greenish feldspar, but in the upper sheets has a white instead of a greenish feldspar. It is of coarse, even-grained texture, the feldspars measuring up to an inch in length and the biotite up to one-fifth inch. It consists, in descending order of abundance, of a pinkish potash feldspar (orthoclase with a little microcline), smoky quartz, a dull greenish or a milk-white soda-lime feldspar (oligoclase) and black mica (biotite) in conspicuous flakes, together with accessory magnetite, pyrite, titanite, and apatite. The orthoclase, generally in twins, is intergrown with a plagioclase. The oligoclase is largely altered to a white mica and kaolin, particularly in the upper sheets, where it has passed from green to a white. The quartz is cloudy from the presence of multitudes of irregular bubbles, the largest of which measure 0.01 mm, or about 0.0004 inch in length. It is also traversed by irregular fissures containing sericite. Some of the pinkish orthoclase is rimmed with white or greenish oligoclase or completely envelopes a greenish oligoclase crystal. The contrasts in the granite of the lower sheets are feeble, owing to the darkness of the oligoclase and quartz, but is marked in that of the upper sheets, the four minerals all differing in shade.

The quarry consists of five openings: (1) 100 by 25 and 14 feet deep; (2) 50 by 25 and 40 feet deep; (3) 300 by 70 and 35 feet deep; (4) triangular, 100 by 150 by 75 feet deep, with working face 35 feet high, and (5) 50 by 25 and 20 feet deep. In places there are 3 feet of "till" stripping. There is no drainage problem, but the opening at the wharf can be operated only at low tide.

Rock structure: The sheets at the upper opening from 2 to 22 feet thick, but usually from 5 to 15 feet, dip 10° NE. Vertical joints striking N. 10° E. or north form a heading on the east and recur at intervals of 5 to 10 feet. Another set strikes east-west and dips 60° S., and one which may belong to it strikes N. 80° W., dips 90°. The rift is horizontal, the grain vertical, trending north-south. Dikes of aplite up to an inch thick have N. 60° E. courses.

The plant consists of 3 derricks worked by horses.

Transportation is effected by cartage of 700 feet and 50 feet down grade from upper opening to wharf. From the opening at the wharf stones are loaded by derricks directly on to schooners.

The product is used for buildings and monuments. Specimen structures: Colorado Building, at Fourteenth and G streets, Washington, D. C.; State armory at Providence, R. I.; power house of the

Metropolitan Street Railway (Interurban), Ninety-fifth to Ninety-sixth streets and First avenue to Hudson River, New York.

The New England granite quarry is in the town of Jonesport, on the south side of Head Harbor Island (Hacketts Harbor). Owner, New England Granite Company, Jonesport, Me.

The granite (specimen 89, *a*) is a biotite granite of general dark reddish-gray color, with both a pinkish and a whitish feldspar, and of coarse, somewhat porphyritic texture, with feldspars up to an inch in diameter and biotite under one-fifth inch. It consists of the same minerals as the granite of the north side of the island, described above. The only perceptible difference is that here the spaces between the feldspars, instead of being filled with quartz, seem to be occupied by a mixture of quartz and fine pinkish orthoclase, and the rock is thus slightly porphyritic. The effect is to diminish the contrast between the quartz and the orthoclase.

The quarry measures 200 by 100, and up to 25 feet in depth.

Rock structure: The sheets, from 3 to 8 feet thick, dip 10°, and are crossed by vertical joints striking N. 10° E., spaced 20 feet or more; also by a set striking east-west and spaced in the same way.

The plant consists of 2 derricks and 2 hoisting engines.

Transportation was effected by means of a track 3,000 feet long to a wharf in Hacketts Harbor.

No work has been done since 1897.

The Hardwood Island quarry is in the town of Jonesport, on Hardwood Island, which lies 3½ miles southwest of Jonesport village. Operator, Rockport Granite Company, Rockport, Mass.

The granite (known commercially as "Moose-a-bec red") is a biotite granite of general dark reddish-gray color, with a white and a pinkish feldspar, and of coarse, even-grained texture, like that of specimen 88, *a*, from Head Harbor Island, described on page 171, but with an occasional isolated feldspar.

The Rosiwal method of determining approximately the proportions of the chief mineral constituents was applied to a specimen of this granite having a polished face measuring 5 by 3 inches. The size of mesh was 0.9 inch; total length of lines, 40.20 inches. Owing to the irregular massing of the feldspars in the specimen a second test was made with the short set of lines shifted one-fourth inch, and the long set adjusted accordingly. The results of both tests were averaged for the final estimate.

Sizes and percentages of minerals in granite from Hardwood Island, as determined by the Rosiwal method.

Mineral.	First test.	Second test.	Averages.	
	Inches.	*Inches.*	*Inches.*	*Per cent.*
Reddish orthoclase	10.12	12.46	11.29	28.85
Milk-white oligoclase	8.00	8.24	8.12	22.45
Biotite	1.72	1.54	1.63	4.05
Smoky quartz	20.36	17.96	19.16	44.65
Total	40.20	40.20	40.20	100.00

Percentage of both feldspars, 51.30.

This granite takes a fine polish, in which the contrasts between the pinkish and white feldspars and the black mica stand out on the background of smoky quartz. Some of the pinkish feldspars are bordered by the white. The large size (usually one-tenth inch) of the biotite scales is against the durability of the polish under long-continued outdoor exposure.

The quarry measures 150 by 60 feet, and 15 feet in depth, but its bottom is between tide levels. There is no stripping.

Rock structure: The sheets, from 2 to 10 feet thick, are horizontal, but in places curve seaward. Joints striking N. 75° W., and dipping 65° S. recur only at rare intervals. Others, striking N. 45° W. and vertical, recur at intervals of 18 feet and over. The rift is vertical with course N. 10° E. Dikes of aplite up to 6 inches thick strike N. 25° W.

The plant consists of 1 derrick. The cutting plant is at Rockport, Mass.

Transportation is effected by lifting the blocks onto the wharf, which is 125 feet from the quarry.

The product is used for buildings and finds a market in Philadelphia, New York, and Baltimore. Specimen buildings: The wainscoting and stairway in main entrance to Suffolk County courthouse in Boston; the American Baptist Publication Society building in Philadelphia, and 25 columns in the Catholic cathedral in Newark, N. J.

The Marshfield quarry is in the town of Marshfield, 3 miles north of Machias. Operator, Machias Granite Company, Machias, Me.

The granite (specimen 84, *b*) is a biotite granite of pinkish-gray color and of medium to fine even-grained texture, with feldspars from one-tenth to two-fifths inch and sparsely disseminated biotite under one-tenth inch in diameter. It consists, in descending order of abundance, of pinkish potash feldspar (orthoclase), smoky quartz, cream-colored soda-lime feldspar (oligoclase), and a little black mica (biotite), together with accessory magnetite, titanite, and zircon and secondary kaolin, white micas, and chlorite. The orthoclase is inter-

grown with plagioclase, the oligoclase is much altered to kaolin and a white mica, and the biotite is partly chloritized. Molybdenite occurs here and there. The granite is slightly less pinkish than that from the quarry of Booth Brothers at Jonesboro (specimen 85, *b*). The contrasts are also reduced by the greater fineness of the particles. It takes a fine polish, the durability of which is favored by the sparseness and smallness of the biotite scales.

The quarry, opened in about 1894, measures 200 by 150 feet and from 2 to 10 feet in depth. There is no serious drainage problem and only 2 feet of soil stripping.

Rock structure: The sheets, from 1 to 8 feet thick, dip irregularly as high as 10° SW. and 10° NW. Vertical joints, striking N. 55° E., form headings on the north and south sides. Another set, striking N. 60° W., dips 70° SW. to 90°, forms headings near the east side, and recurs at intervals of 10 to 50 feet. A third and diagonal set, striking N. 85° E., dips 55° N. and recurs irregularly. There is some "toeing in" of sheets, probably owing to faulting along the set of joints striking N. 55° E. The faces of the second set are coated with epidote and those of the third with pyrite. The rift is horizontal. There are geodes (up to 6 inches thick) of orthoclase and oligoclase, smoky quartz, amethyst, and pyrite filled with calcite, epidote, and chlorite. Sap is 2 inches thick in the upper sheets only.

The plant consists of 2 derricks (1 horse and 1 hand).

Transportation is by cartage of 3 miles to railroad or wharf at Machias.

The product is used for monuments and buildings and finds a market in the Middle West, New York, and Pennsylvania. Specimen buildings: Basement front and steps of E. S. Draper residence, on Beacon street, Boston, Mass. In 1905 the quarry was producing monuments for local demand and for Boston.

The Millbridge quarry is in the town of Millbridge, near Millbridge village, in the southwestern part of Washington County. Operators, Swanton & Wallace, Millbridge, Me.

The granite (specimen 143, *a*) is a biotite granite of somewhat dark buff color and of medium, even-grained texture, with feldspars up to three-tenths inch (exceptionally one-half inch) and biotite scales under one-tenth inch, consisting, in descending order of abundance, of a buff-colored potash feldspar (orthoclase), smoky quartz, very slighty greenish white soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite and apatite. The quartz has numerous very irregular bubbles up to 0.028 millimeter in length. The orthoclase is intergrown with a plagioclase. Granulation ("crush borders") occurs along the contacts of the feldspars with one another. The stone takes a high polish, the durability of which is favored by the smallness of the biotite scales.

Some tests of a Millbridge granite, quarried at White Rock Mountain by S. L. Treat & Co., were made in 1895 by the United States Ordnance Department at the Watertown Arsenal.[a] These give it a shearing strength of 2,820 pounds, a transverse strength of 2,069 pounds, and a compressive strength of 19,917 pounds, all per square inch.

The Millbridge quarry was not visited by the writer, and the firm failed to reply to questions as to dimensions of quarry, plant, and product.

YORK COUNTY.

The granite quarries in York County are in the towns of Alfred, Berwick, Biddeford, Hollis, Kennebunkport, and Wells.

The Bennett quarry is in the town of Alfred, 1 mile southwest of Alfred village, south of Portland and Rochester Railroad, at the north foot of a 480-foot hill. Operator, Bennett Brothers (John H. and Edward), Alfred, Me.

The rock (specimen 153, *a*) is a quartz diorite of slightly greenish dark-gray color, with conspicuous black mica, and of medium, even-grained texture, with feldspars up to one-fourth inch and biotite scales under one-fifth inch. It consists, in descending order of abundance, of a grayish soda-lime feldspar (oligoclase), black mica (biotite), quartz (smoky or milky), dark hornblende and magnetite, with accessory titanite, zircon, apatite, and secondary epidote and a white mica. The oligoclase is often in good-sized twins and is intergrown with orthoclase and quartz, and generally cloudy and altered by a white mica. The only contrast in this stone is that between the gray of the feldspar and quartz and the black mica. After one or two years' exposure the feldspar loses its slightly bluish tinge and assumes a greenish one, which is attributed to the oxidation of its ferrous oxide. (See on this subject p. 54.)

The quarry, opened prior to 1875, measures 60 by 150 and is up to 30 feet in depth.

Rock structure: The sheets, measuring up to 12 feet in thickness and inclined, are crossed by vertical joints striking N. 70° E., recurring at intervals of 10 feet and forming a heading 8 feet wide in center of quarry. Another set, also vertical, and striking N. 20°–25° W., recurs at intervals of 20 feet. The rift is horizontal and the grain vertical, with course N. 70° E. The sap is 2 inches thick along the sheets. A vertical bed of sand, 6 inches thick, lies in the central heading.

The plant consists of 1 hand derrick.

Transportation is effected by cartage of a mile to Alfred railroad station.

[a] Rept. of tests of metals, etc., for 1895 (1896), pp. 319, 325, 344, 409.

The product is used for curbing and buildings, and finds a market in Rochester, N. H. The Parsons Memorial Library, of Alfred village, is built of this stone.

The Spence & Coombs black-granite quarry is in the town of Berwick, 1½ miles southeast of North Berwick village and station. Operator, Spence & Coombs, Berwick, Me.

This rock (specimen 139, *a*) is a gabbro of very dark olive-brownish color and medium ophitic texture, consisting, in descending order of abundance, of longitudinal crystals of grayish olive-brownish lime-soda feldspar (labradorite) between which are particles of diallage, black mica (biotite), magnetite, and a little pyrite, together with secondary hornblende, analcite, zoisite, and calcite. The freshly quarried stone becomes somewhat brownish on exposure. It takes a high polish and the cut or hammered surface is almost white.

The quarry consists of two openings, about 25 feet square by 5 to 10 feet deep.

Rock structure: The sheets, from 6 to 8 feet thick, lie nearly horizontal, and are crossed by vertical joints striking N. 25°–30° W. and by another set striking N. 45° E. and dipping 65° SE. and recurring at intervals of 6 to 20 feet.

The plant consists of 2 derricks.

The quarry is worked only occasionally and the stone is used entirely for monuments. In 1905 a carload of it was shipped to Concord, N. H. A monument made of this gabbro for a Mr. Johnson was erected in 1885 in a cemetery at Somersworth, N. H., and is reported to be in as good condition now as then.

The Ricker quarry is in Biddeford city, at 19 Granite street. Operator, Charles Ricker, 19 Granite street, Biddeford.

The granite (specimen 129, *a*) is a biotite granite of general light-gray shade with conspicuous smoky quartz and slightly bluish white feldspar and of coarse, even-grained texture, with feldspars up to 0.75 inches and biotite under 0.2 inches. It consists, in descending order of abundance, of a slightly bluish milk-white potash feldspar (microcline and orthoclase), quite smoky quartz, milk-white soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite, zircon, and apatite, and secondary white mica and kaolin, derived from the alteration of the oligoclase. The contrasts in this granite are unusually brilliant. They are between the white of the feldspars, the gray of the very vitreous quartz, and the black of the mica. The stone takes a fine polish, but the largeness of the biotite scales does not favor its durability under exposure to the weather.

The quarry, opened in 1865, is 100 by 50 and from 5 to 25 feet deep. There is no drainage problem nor stripping.

Rock structure: The sheets, up to 12 feet thick, are crossed by joints striking N. 50° E., and dipping 55° NW., which recur at intervals of 2 to 20 feet, and by a set striking N. 45° W., and dipping 60° SW., which recur at intervals of 2 to 10 feet and over.

The plant consists of 5 derricks and 1 engine.

Transportation involves cartage of 1 mile to railroad.

The product is used for monuments, etc.

The Gowen Emmons quarry is in Biddeford city, at 17 Granite street. Operator, Gowen Emmons & Co., 17 Granite street, Biddeford.

The granite (specimen 128, *a*) is a biotite granite of general light-gray shade, with conspicuous smoky quartz and slightly bluish white feldspar, and of coarse even-grained texture, with feldspars up to three-fourths inch and biotite under one-fifth inch. It is

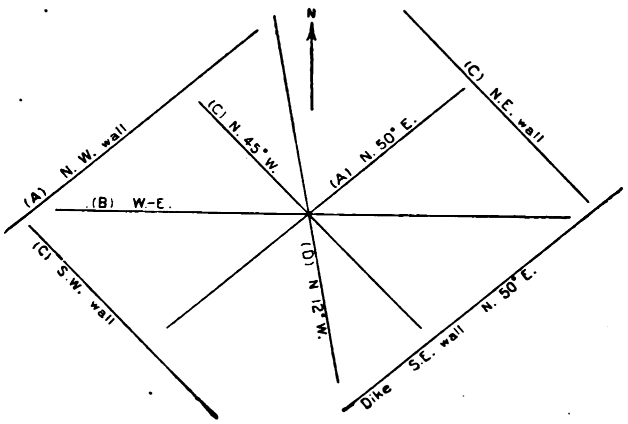

FIG. 38.—Structure at the Gowen Emmons quarry, Biddeford.

identical with that of the Ricker quarry (specimen 129, *a*), described above. In the sheets that lie nearer the surface the feldspar has lost its bluish tint and is slightly grayish or greenish, which has the effect of diminishing the contrasts. Specimen 128, *a* is not so brilliant as 129, *a*.

The quarry, opened about 1865, consists of 2 openings, an old one 200 feet from northeast to southwest, by 100 feet across, and from 30 to 70 feet deep, and a new one, 250 feet from northeast to southwest, by 200 across, and from 10 to 60 feet in depth. There is no drainage problem.

Rock structure: The sheets, from 1 to 12 feet 6 inches thick, increasing in thickness downward, undulate horizontally. The joint courses are shown in fig. 38. A dips 55° NW., and recurs at intervals of 2 to 20 feet; B dips 70° S., and occurs exceptionally; C dips

60° SW., and forms the northeast and southwest walls, and recurs at intervals of from 2 to 10 feet or more; D dips 65° E., and occurs exceptionally. The rift is vertical, N. 60° W.; grain is horizontal. On the southeast wall there is a basic dike up to 1 foot thick and nearly parallel to joints A. Black knots occur up to 6 inches across. Sap measures 6 inches on both sides of upper sheets but diminishes below.

The plant consists of 5 derricks, 2 hoisting engines, and 2 polishers, run by an 8-horsepower engine.

Transportation involves cartage of 1 mile to railroad.

The product is used for buildings and monuments, and finds a market in the State and also in the West. Specimen monument: The Lincoln monument, erected at Springfield, Ill., in 1868. Contract in 1905: A hospital at Dover, N. H.

The Marcille & Wormwood quarry is in the town of Biddeford, 1¼ miles southwest of Biddeford city, in West Biddeford. Operator, Marcille & Wormwood, Biddeford.

The granite (specimen 130, *a*) is a biotite granite of general medium-gray pinkish-buff color and of coarse, even-grained texture, with feldspars up to three-fourths inch and biotite up to three-twentieths inch. It consists, in descending order of abundance, of a pinkish-buff potash feldspar (microcline and orthoclase), dark smoky quartz, cream-white soda-lime feldspar (oligoclase), black mica (biotite), and a very little muscovite, together with accessory magnetite and secondary epidote, chlorite, kaolin, and white micas. The oligoclase is considerably altered to kaolin, a white mica, and epidote, and the biotite to chlorite. The contrasts in this stone are chiefly between the pinkish-buff and the white feldspars and the smoky quartz, to which the black mica adds another element. As some of the potash feldspars are more pink and others more buff, it has in all five colors and shades.

The quarry is 40 by 20 feet and from 6 to 8 feet deep. There is little or no stripping.

Rock structure: The sheets, 7 feet thick (increasing to 15 feet lower down the hill), are crossed by vertical or very steep joints, striking N. 80°–85° W., which recur at intervals of 20 feet, also striking N. 40° E., and recurring at intervals of 35 feet with headings. Sap, 1 to 2 inches thick, occurs along the top sheet, but along the headings it is 4 inches thick. A bunch of knots up to 8 inches thick and of egg-shaped outline was noticed.

The plant consists of 3 derricks.

Transportation involves a cartage of 1 mile to railroad siding.

The product is used for buildings. Specimen building: The trimmings on St. Joseph's Church, at Biddeford. (Material for the Charlestown, Mass., dry dock was quarried at an old opening adjacent

to this.) In 1905 the quarry was producing trimmings for St. Mary's Convent, at Biddeford.

The Andrews & Perkins quarries are in the town of Biddeford, about 1½ miles southeast of Biddeford city and one-half mile south of Saco River. Operator, Andrews & Perkins, 18 Middle street, Biddeford.

The granite (specimen 133, *a*) is a biotite granite of general light-gray color, with conspicuous black mica, and of coarse, even-grained texture, with feldspars up to three-fourths inch and biotite up to one-fifth inch. It consists, in descending order of abundance, of a bluish, translucent white potash feldspar (microcline and orthoclase), smoky quartz (not so dark as that of the Ricker quarry, specimen 120, *a*) milk-white soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite, titanite, zircon, and apatite and secondary kaolin and a white mica derived from the alteration of the oligoclase. The feldspars are considerably intergrown with quartz, some particles of which are circular in cross section. The contrasts are chiefly between the feldspars, quartz, and mica. The feldspar is more bluish than that of the Ricker and Gowen Emmons quarries.

The quarries, opened in 1862, and again in 1895, consist of six small openings of various dimensions, only one of which—a "bowlder quarry"—is worked at present.

Rock structure: The rift is horizontal, the grain vertical, striking northwest-southeast, but the difference between them is not marked. The jointing permits the quarrying of blocks up to 25 feet square. Sap is 2 inches thick. Knots in some of the openings measure up to 3 and even 10 feet in length.

The plant consists of 10 derricks, 3 hoisting engines, 4 steam drills, and 4 pumps.

Transportation involves cartage of one-half mile to Saco River, or of 2 miles to railroad at Biddeford.

The product is used for buildings and monuments. Specimen buildings: Tribune Building, New York; General Dix monument at Fort Monroe, Va.; foundation and trimmings of Watson & Miller building at Portland, Me. This quarry has furnished granite for the Delaware and Saco River breakwaters. In 1905 the quarry was supplying curbing for Dover and Rochester, N. H.

The Goodwin quarry is in the town of Biddeford, about 1½ miles southeast of Biddeford city and one-half mile south of Saco River, a little southeast of Andrews & Perkins quarry. Owner, Goodwin heirs, Biddeford. The quarry is not in operation.

The granite is a biotite granite, identical with that of the Andrews & Perkins quarry, described above.

The quarry consists of two openings, one 150 feet square and 10 to 25 feet deep, another 200 by 150 feet and from 10 to 40 feet deep.

Rock structure: The sheets, from 1 to 10 feet thick, are horizontal, undulating, or dip up to 15° SE. with a 3-inch bed of sand in upper part. Joints, striking N. 45° E. and dipping 65° NW., form a heading in the newer opening, and in the older one recur at intervals of 1 to 5 feet. Another set, confined to the newer opening, striking N. 50° W., and dipping 90°, forms the northeast and southwest walls of the quarry and a 10-foot heading in the middle. Knots are somewhat plentiful. An 18-inch basic dike strikes northeast.

The plant consists of 4 derricks and 1 hoisting engine.

The Bear Hill quarry is in the town of Hollis, on Bear Hill, 1 mile west-southwest of Bradbury station (Hollis Center), on the Portland and Rochester Railroad. Operator, E. M. Bradbury, Hollis Center, Me.

The granite (specimen 136, *a*) is a biotite-muscovite granite of medium-gray shade with a slight greenish tinge, evenly spangled with black and white mica, and of medium (inclining to fine) even-grained texture, with feldspar up to three-tenths and mica up to one-tenth inch. It consists, in descending order of abundance, of a grayish potash feldspar (orthoclase and microcline), slightly smoky quartz, grayish soda-lime feldspar (oligoclase), black and white mica (biotite and muscovite), with accessory apatite and a secondary white mica. As the quartz is about of the same shade as the feldspar the only contrast is between the gray ground and the micas. In the stone at the smaller openings the feldspars are milk-white translucent, with a very slight bluish tinge, which gives the granite a general light-gray shade.

The quarry, opened in 1901 (although stone had been taken out as early as 1855), consists of an older opening of irregular shape, from which about 700 cubic yards have been quarried and an acre stripped, and of a newer opening 50 feet square and 5 to 10 feet deep. The stripping consists of 1 foot of soil (woods).

Rock structure: The sheets are lenticular, up to 6 feet thick, and horizontal. Vertical joints strike N. 55° W., and form a heading on the southwest; joints also strike N. 30°–35° E., recurring at intervals of 30 feet or more. The rift (horizontal) is marked, and the grain is vertical, striking east and west. Pegmatite dikes, up to 6 feet thick, strike N. 10°–20° W., recurring at intervals of 30 feet or more, and in places branching. They consist of quartz, feldspar, biotite, and muscovite. A basic dike, from 1 to 12 inches thick and with a course N. 30° E., traverses the entire quarry, crossing the pegmatite dikes and dying out on the northeast. The sap is marked on upper sheet and also along the joints and up to 6 inches in thickness.

The plant consists of 3 derricks and 1 ditch hand pump.

Transportation involves a cartage of one-fourth mile to railroad, but the present contract for dam on Saco River involves a cartage of 3 miles.

The product is "random stone." The quarry is now producing stone for the foundation of a pulp mill (Bar Mills) and for a dam on the Saco River.

The Day quarry is in the town of Kennebunkport, 3 miles southwest of Biddeford. Operator, A. H. Day, Biddeford.

The granite (specimen 131, *a*) is a biotite-muscovite granite of medium-gray shade with conspicuous black mica and of coarse even-grained texture, with feldspars up to an inch across and biotite scales up to one-fifth inch. It consists, in descending order of abundance, of a gray (very slightly buff-pinkish in places) potash feldspar (microcline and orthoclase), very smoky quartz, milk-white soda-lime feldspar (oligoclase), black mica (biotite), with a little white mica (muscovite). The contrasts in this granite are marked.

The quarry, opened about 1899, is 50 feet square and 25 to 30 feet deep. The stripping consists of 3 feet of gravel.

Rock structure: The sheets, from 4 to 14 feet thick, dip 10° E.; joints, striking north and dipping 60° W., form a heading on the west, and recur at intervals of 30 feet or more. One striking northwest dips 80° SW.; another strikes N. 80° E., and still another strikes northeast and dips 40° SE. This is a bowlder quarry. The rift is horizontal and grain N. 70°–75° W., but they are not marked. Sap, from 2 to 3 inches thick, occurs along the joints.

The plant consists of 6 derricks and 1 hoisting engine.

Transportation involves cartage of 1 mile to a railroad siding.

The product is used for bridge work, and some of it was used in the Kittery, Me., dry dock. In 1905 the quarry was doing bridge work for the Boston and Maine Railroad.

The Ross quarry is in the town of Kennebunkport, 3½ miles southwest of Biddeford. Operator, Ellis & Buswell; office at Woburn, Mass.

The granite (specimen 132, *a*) is a biotite granite of general light-gray shade with translucent milky-white feldspars, dark, smoky quartz and black mica, and of coarse, even-grained texture with feldspars up to 1 inch across and biotite scales under one-fifth inch. It is similar to that of the Ricker and Gowen Emmons quarries, described on pages 175, 176.

The quarry, opened in 1887, is about 200 feet square and 35 feet in depth. Its drainage requires pumping after each rain and for a month in the spring before starting up. The stripping consists of 2 to 3 feet of loam.

Rock structure: This is a typical "bowlder quarry," with irregular joints, shown in fig. 39. The sheets, from 14 to 22 feet thick,

are horizontal or dip 30° E., but irregularly. A basic dike 10 inches thick forms the northwest side of the quarry and is said to continue for one-fourth mile in a direction N. 50° E. The joints run in four directions, none of them at right angles to another and none of them vertical. Sap measures from 3 to 6 inches thick along the sheets. Knots up to 6 inches thick are not abundant.

The plant consists of 6 derricks, 2 hoisting engines, 2 steam drills, and 2 steam pumps.

Transportation involves cartage of one-third mile to a siding on the Boston and Maine Railroad.

The product is used mostly for bridge work. Specimen structures: The gateway at Hope Cemetery, in Kennebunk (except the balls on the posts) and the Renwick tomb at cemetery near Kittery, Me. Contract in 1905: Railroad bridge at Haverhill, Mass.

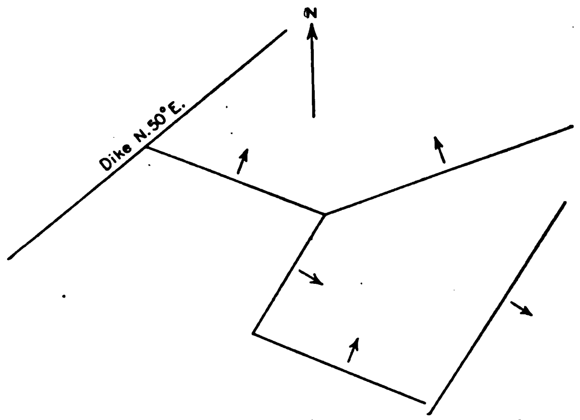

FIG. 39.—Approximate structure at Ross (Ellis & Buswell) "bowlder quarry," Kennebunkport. The small arrows show the direction of dip of joints.

The Lord prospect is in the town of Wells about 1 mile east-northeast of Wells Depot on the Boston and Maine Railroad (eastern division), near a schoolhouse at a road fork. Owners: Granville W. and H. E. Lord (of one opening). These, associated with L. A. Stevens, are owners of another opening. Address, Wells Depot, Me.

The granite from the first opening (specimen 138, *a*) is a biotite granite of light pinkish-gray shade, with sparsely disseminated conspicuous biotite, and of medium to coarse, even-grained texture, with feldspars up to one-half inch and biotite scales up to one-fifth inch in diameter. It consists, in descending order of abundance, of a delicate pink potash feldspar (microcline and orthoclase), with slightly smoky quartz, cream-white soda-lime feldspar (oligoclase), and black mica (biotite), together with accessory magnetite and zircon and secondary white mica and chlorite. The potash feldspars are both intergrown with plagioclase. The oligoclase is intergrown with

quartz in particles that are circular in cross section and is partly altered to a white mica and the biotite to chlorite.

The stone takes a good polish, but the large size of the biotite scales is not favorable to the durability of the polish in outdoor exposure. The contrasts are chiefly between the grayish-pinkish ground and the black mica.

The openings are small. The stripping consists of 3 feet of sand. The sheets, from 1 to 3 feet thick, are horizontal. Vertical joints strike N. 10° E. and N. 70° W. The rift is horizontal. Sap 2 inches thick occurs along the sheets.

STATISTICS OF EQUIPMENT AND INVESTMENT.

In order to ascertain the amount of capital invested in the Maine granite industry, the operators were asked to submit, in confidence, conservative estimates of the value of their quarries and plants and of an amount of capital sufficient for working the same on their present scale. Figures were obtained from all but a few very small concerns, and in their cases estimates were made by the writer based on the size of the quarries and plants and the number of men employed and on the returns from the other firms. The figures for 82 operators aggregate $3,531,000, but four of these operators are simply owners of idle quarries. As their value was estimated at $73,500, that amount should perhaps be deducted from the aggregate, which would make the investment represented by the Maine granite industry $3,467,000, or, in round numbers, $3,500,000.

STATISTICS OF PRODUCTION FOR 1905.

By Altha T. Coons.

The following table shows the production of granite in Maine in 1905, classified by counties and by uses:

Production of granite in Maine in 1905, by counties and uses.

County.	Building stone.		Monumental stone.		Paving blocks.	
	Rough.	Dressed.	Rough.	Dressed.	Number of blocks.	Value.
Hancock	$261,168	$465,833	$1,125	$1,500	3,122,561	$129,085
Knox	49,222	204,976	18,323	4,200	3,451,196	140,816
Waldo	6,630	272,000	2,098	....	996,546	30,557
Franklin	13,510	251,357	....	....	125,641	5,025
Kennebec	1,000	214,092	4,730	25,014	55,652	2,175
Lincoln	861	207,900	4,000	4,700	370,000	14,800
Washington	66,000	18,619	42,139	24,676	....	....
York	20,666	4,576	2,068	5,845	5 000	300
Cumberland	5,567	5,000	1,050	1,200	12,000	600
Somerset	2,512	1,312	1,010	1,500	....	....
Oxford	2,266	522	1,000	400	10,000	300
Penobscot, Aroostook	5,000	2,500	....	875	40,000	1,200
Total	434,402	1,648,687	77,543	69,910	8,188,596	324,858

Production of granite in Maine in 1905, by counties and uses—Continued.

County.	Curbing.	Flag-stone.	Crushed stone.	Rubble.	Riprap.	Other.	Total.
Hancock	$60,141	$8,720				$1,300	$928,872
Knox			$724	$710	$875	23,140	442,486
Waldo			875			10,523	322,683
Franklin	1,280		6,016	1,975			279,163
Kennebec	73			2,538		943	250,565
Lincoln			2,495		100	430	235,286
Washington						10,000	161,434
York	5,696	600	10			4,172	43,933
Cumberland	4,770		100			800	19,087
Somerset					900	4,452	11,686
Oxford	1,800	400	96		300	1,000	8,084
Penobscot, Aroostook	941						10,516
Total	74,701	9,720	10,316	5,223	1,675	56,760	2,713,795

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The German periodicals named below also give results of tests of granite:

Mitteilungen der technischen Versuchsanstalten zu Berlin.

Mitteilungen der Anstalt zur Prüfung von Baumaterialien am Polytechnikum in Zürich.

Mitteilungen aus dem mechanisch-technischen Laboratorium der Königlichen technischen Hochschule in München.

The substance of the paper by Merrill in vol. 10 of the United States Tenth Census, 1888, and by Merrill in the proceedings of the U. S. National Museum, vol. 6, 1883, several times referred to, has reappeared in more modern form in his other works or is given in this report.

GLOSSARY OF SCIENTIFIC AND QUARRY TERMS.

ACCESSORY MINERALS in granite are original constituents of the rock, found only in small, often only in microscopic quantity. (See p. 17.)

ANTICLINE. A term applied to granite sheets or sedimentary beds that form an arch.

APLITE. Fine-grained granite, usually occurring in dikes and containing little mica and a high percentage of silica.

BASIC. A term applied to rocks in which the iron-magnesia minerals and feldspars with lime and soda predominate, such as diabase or basalts.

BOWLDER QUARRY. One in which the joints are either so close or so irregular that no very large blocks of stone can be quarried.

CHANNEL. A narrow artificial incision across a mass of rock, which, in the case of a granite sheet, is made either by a series of contiguous drill holes or by blasting a series of holes arranged in zigzag order.

CLEAVAGE, when applied to a mineral, designates a structure consequent upon the geometrical arrangement of its molecules at the time of its crystallization.

CLOSE-JOINTED. A term applied to joints that are very near together.

CRUSH-BORDER. A microscopic granular structure sometimes characterizing adjacent feldspar particles in granite in consequence of their having been crushed together during or subsequent to their crystallization.

CUT-OFF. Quarrymen's term for the direction along which the granite must be channeled, because it will not split. Same as "hard-way."

DIKE. A mass of granite, diabase, basalt, or other rock which has been erupted through a narrow fissure.

DIMENSION STONE. A term applied to stones that are quarried of required dimensions.

Dip. The inclination from the horizon, given in terms of degrees, of a sheet, joint, heading, dike, or other structural plane in a rock.

Drift. Sand and bowlders deposited by the continental glacier.

Erosion. The wearing away of portions of a rock by such natural agencies as stream or ice action.

Exfoliation. The peeling of a rock surface in sheets owing to changes of temperature or other causes.

Faulting. The slippage of a rock mass or masses along a natural fracture. (See p. 40.)

Flow structure. The parallel arrangement of the minerals in granite or other igneous rock in the direction of its flowage during its intrusion. (See p. 25.)

Geode. A rock cavity lined with crystals. Geodes in granite are attributed to steam or gas bubbles. (See p. 50.)

Grain in granite is practically the direction in which the stone splits "next easiest," the "rift" being that in which it splits most readily. (See p. 26.)

Grout. A term applied to the waste material of all sizes obtained in quarrying stone.

Grow-on. Quarrymen's term to designate the place where the sheet structure dies out, or the place where two sheets appear to grow onto one another.

Hard-way. The direction at right angles to both rift and grain in which granite does not split readily. (See Cut-off.)

Heading. A collection of close joints. (See p. 39, and Pls. VIII, *A*, IX, *B*.)

Heading-seam. See Joint.

Hematite. An oxide of iron (Fe_2O_3) which when scratched or powdered gives a cherry-red color.

Igneous. A term applied to rocks that have originated in a molten condition.

Joints. More or less steeply inclined fractures which cross the granite sheets and which are attributed to various stresses. (See p. 38.)

Kaolin. A hydrous silicate of alumina derived from the alteration of feldspar.

Kaolinization. The process by which a feldspar passes into kaolin. (See p. 55.)

Knots. A term applied by quarrymen to dark gray or black objects, more or less oval or circular in cross-section, which are segregations of black mica or hornblende formed in the granite while in a molten state. (See p. 49.) English quarrymen call them "heathen."

Knox hole. A circular drill hole with two opposite vertical grooves which direct the explosive power of the blast.

Lewis hole. An opening made by drilling two or three holes near together and chiseling out the intervening rock.

Limonite. A hydrous oxide of iron ($2Fe_2O_3$, $3H_2O$); a hydrated hematite, which, when scratched or powdered, gives a brownish rust color.

Matrix. The general mass of a rock which has isolated crystals; sometimes called groundmass.

Millimeter. French decimal lineal measure, the thousandth part of a meter or the tenth part of a centimeter. It is equivalent to nearly 0.04 inches, the meter being $39\frac{10}{27}$ inches.

Monolith. A column or monument of one stone.

MOTION. A term used in granite regions to designate small paving-block quarries. (See Pl. XII, *B*.)

OPHITIC. A term applied to microscopic rock texture to designate a mass of longish interlacing crystals, the spaces between which have been filled with minerals of later crystallization.

PEGMATITE. A very coarse granite occurring in irregular dikes or lenses in granites and some other rocks. (See p. 44.)

PLAGIOCLASE. A term applied to all those feldspars that are not potash feldspars.

POLARIZED LIGHT. Light whose vibrations, unlike those of ordinary light, which are in all directions, are in only one plane. Polarized light is used in the microscopic study of rocks.

PORPHYRITIC. A term applied to rock texture to designate the presence of isolated crystals in a general mass (matrix or groundmass) of finer material. (See p. 20.)

RANDOM STONE. A term applied by quarrymen to quarried blocks of any dimensions. (See definition of dimension stone.)

RIFT. A quarrymen's term to designate an obscure microscopic cleavage in granite which greatly facilitates quarrying. (See p. 26 and fig. 28.)

SALT-HORSE. Quarrymen's term for aplite.

SAP. Quarrymen's term for ferruginous discoloration along sheet or joint surfaces.

SCHIST. A rock made up of flattish particles arranged in rough parallelism, some or all of which have crystallized under pressure.

SCHISTOSITY. The quality of being like a schist.

SEAM. Quarrymen's term for joint.

SECONDARY MINERALS. Minerals whose presence is due to the alteration of the original minerals.

SEDIMENTARY. A term designating those rocks that consist of particles deposited under water.

SEGREGATION. The scientific term for "knot;" a collection of material separated from other material.

SERICITE. A more or less fibrous form of muscovite (potash mica), often resulting from the alteration of feldspar.

SHAKES. Quarrymen's term to designate a somewhat minute close-joint structure, which forms along the sheet surface as a result of weathering. (See p. 40.)

SHEET QUARRY. A quarry in which the granite lies in sheets, crossed by wide-spaced steep joints.

SLICKENSIDES. The polished and grooved faces of a joint or bed caused by motion and friction.

SPECIFIC GRAVITY. The weight of a rock or mineral compared to that of a body of distilled water of the same bulk. (See p. 21.)

STRATIFIED. A term applied to rock consisting of originally horizontal beds or strata.

STRIKE. The direction at right angles to the inclination of a plane of bedding, a sheet, or joint, etc.

STRIPPING. The material (sand, clay, soil, etc.) overlying a rock of economic value, which must be removed before quarrying.

SUBJOINT. Minor joints diverging from or parallel to the regular joints. (See p. 41.)

SYNCLINE. A geological term for the trough part of a wavelike sheet or bed of rock.

TILL. A mixture of clay and bowlders deposited by glaciers.

TOEING-IN. Quarrymen's term for the wedging in of the end of a granite sheet under an overhanging joint, probably in consequence of the faulting of the sheets along the joint. It is also applied to the overlapping of lenticular sheets.

TWIN CRYSTALS. Two adjacent crystals which have formed with the poles of their main axes in opposite or different directions. (See p. 20.)

WEATHERING. The decomposition of a rock owing to the action of the weather. (See p. 54.)

INDEX.

H.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 313.]

The publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress for distribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.
4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports; Q, Fuels; R, Structural materials. This paper is the ninety-third in Series A, the complete list of which follows (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

SERIES A, ECONOMIC GEOLOGY.

B 21. Lignites of Great Sioux Reservation: Report on region between Grand and Moreau rivers, Dakota, by Bailey Willis. 1885. 16 pp., 5 pls. (Out of stock.)

B 46. Nature and origin of deposits of phosphate of lime, by R. A. F. Penrose, jr., with introduction by N. S. Shaler. 1888. 143 pp. (Out of stock.)

B 65. Stratigraphy of the bituminous coal field of Pennsylvania, Ohio, and West Virginia, by I. C. White. 1891. 212 pp., 11 pls. (Out of stock.)

B 111. Geology of Big Stone Gap coal field of Virginia and Kentucky, by M. R. Campbell. 1893. 106 pp., 6 pls. (Out of stock.)

B 132. The disseminated lead ores of southeastern Missouri, by Arthur Winslow. 1896. 31 pp. (Out of stock.)

B 138. Artesian-well prospects in Atlantic Coastal Plain region, by N. H. Darton. 1896. 228 pp., 19 pls.

B 139. Geology of Castle Mountain mining district, Montana, by W. H. Weed and L. V. Pirsson. 1896. 164 pp., 17 pls.

B 143. Bibliography of clays and the ceramic arts, by J. C. Branner. 1896. 114 pp.

B 164. Reconnaissance on the Rio Grande coal fields of Texas, by T. W. Vaughan, including a report on igneous rocks from the San Carlos coal field, by E. C. E. Lord. 1900. 100 pp., 11 pls. (Out of stock.)

B 178. El Paso tin deposits, by W. H. Weed. 1901. 15 pp., 1 pl.

B 180. Occurrence and distribution of corundum in United States, by J. H. Pratt. 1901. 98 pp., 14 pls. (Out of stock; see No. 269.)

B 182. A report on the economic geology of the Silverton quadrangle, Colorado, by F. L. Ransome. 1901. 266 pp., 16 pls. (Out of stock.)

B 184. Oil and gas fields of the western interior and northern Texas Coal Measures and of the Upper Cretaceous and Tertiary of the western Gulf coast, by G. I. Adams. 1901. 64 pp., 10 pls. (Out of stock.)
B 193. The geological relations and distribution of platinum and associated metals, by J. F. Kemp. 1902. 95 pp., 6 pls.
B 198. The Berea grit oil sand in the Cadiz quadrangle, Ohio, by W. T. Griswold. 1902. 43 pp., 1 pl. (Out of stock.)
PP 1. Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of the geology of southeastern Alaska, by A. H. Brooks. 1902. 120 pp., 2 pls.
B 200. Reconnaissance of the borax deposits of Death Valley and Mohave Desert, by M. R. Campbell. 1902. 23 pp., 1 pl. (Out of stock.)
B 202. Tests for gold and silver in shales from western Kansas, by Waldemar Lindgren. 1902. 21 pp. (Out of stock.)
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PP 10. Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, by way of Dall, Kanuti, Allen, and Kowak rivers, by W. C. Mendenhall. 1902. 68 pp., 10 pls.
PP 11. Clays of the United States east of the Mississippi River, by Heinrich Ries. 1903. 298 pp., 9 pls. (Out of stock.)
PP 12. Geology of the Globe copper district, Arizona, by F. L. Ransome. 1903. 168 pp., 27 pls.
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B 213. Contributions to economic geology, 1902; S. F. Emmons and C. W. Hayes, geologists in charge. 1903. 449 pp. (Out of stock.)
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B 218. Coal resources of the Yukon, Alaska, by A. J. Collier. 1903. 71 pp., 6 pls.
B 219. The ore deposits of Tonopoh, Nevada (preliminary report), by J. E. Spurr. 1903. 31 pp., 1 pl. (Out of stock.)
PP 20. A reconnaissance in northern Alaska in 1901, by F. C. Schrader. 1904. 139 pp., 16 pls.
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PP 26. Economic resources of the northern Black Hills, by J. D. Irving, with contributions by S. F. Emmons and T. A. Jaggar, jr. 1904. 222 pp., 20 pls.
PP 27. A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho, by Waldemar Lindgren. 1904. 123 pp., 15 pls.
B 229. Tin deposits of the York region, Alaska, by A. J. Collier. 1904. 61 pp., 7 pls.
B 236. The Porcupine placer district, Alaska, by C. W. Wright. 1904. 35 pp., 10 pls.
B 238. Economic geology of the Iola quadrangle, Kansas, by G. I. Adams, Erasmus Haworth, and W. R. Crane. 1904. 83 pp., 11 pls.
B 243. Cement materials and industry of the United States, by E. C. Eckel. 1905. 395 pp., 15 pls.
B 246. Zinc and lead deposits of northwestern Illinois, by H. Foster Bain. 1904. 56 pp., 5 pls.
B 247. The Fairhaven gold placers of Seward Peninsula, Alaska, by F. H. Moffit. 1905. 85 pp., 14 pls.
B 249. Limestones of southeastern Pennsylvania, by F. G. Clapp. 1905. 52 pp., 7 pls.
B 250. The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits, by G. C. Martin. 1905. 65 pp., 7 pls.
B 251. The gold placers of the Fortymile, Birch Creek, and Fairbanks regions, Alaska, by L. M. Prindle. 1905. 89 pp., 16 pls.
WS 117. The lignite of North Dakota and its relation to irrigation, by F. A. Wilder. 1905. 59 pp., 8 pls.
PP 36. The lead, zinc, and fluorspar deposits of western Kentucky, by E. O. Ulrich and W. S. T. Smith. 1905. 218 pp., 15 pls.
PP 38. Economic geology of the Bingham mining district, Utah, by J. M. Boutwell, with a chapter on areal geology, by Arthur Keith, and an introduction on general geology, by S. F. Emmons. 1905. 413 pp., 49 pls.
PP 41. Geology of the central Copper River region, Alaska, by W. C. Mendenhall. 1905. 133 pp., 20 pls.
B 254. Report of progress in the geological resurvey of the Cripple Creek district, Colorado, by Waldemar Lindgren and F. L. Ransome. 1904. 36 pp.
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B 260. Contributions to economic geology, 1904; S. F. Emmons and C. W. Hayes, geologists in charge. 1905. 620 pp., 4 pls.
B 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, and M. R. Campbell, committee in charge. 1905. 172 pp. (Out of stock.)
B 263. Methods and cost of gravel and placer mining in Alaska, by C. W. Purington. 1905. 273 pp., 42 pls. (Out of stock.)
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PP 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. (In 3 parts.) 1,492 pp., 13 pls.
B 275. Slate deposits and slate industry of the United States, by T. N. Dale, with sections by E. C. Eckel, W. F. Hillebrand, and A. T. Coons. 1906. 154 pp., 25 pls.
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B 278. Geology and coal resources of the Cape Lisburne region, Alaska, by A. J. Collier. 1906. 54 pp., 9 pls. (Out of stock.)
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THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

REPORT

ON

PROGRESS OF INVESTIGATIONS OF MINERAL RESOURCES OF ALASKA

IN

1906

BY ALFRED H. BROOKS AND OTHERS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1907

CONTENTS.

ILLUSTRATIONS.

REPORT ON PROGRESS OF INVESTIGATIONS OF MINERAL RESOURCES OF ALASKA IN 1906.

By Alfred H. Brooks and others.

ADMINISTRATIVE REPORT.

By Alfred H. Brooks.

PREFACE.

This volume, like those previously issued,[a] will (1) summarize the results of the field work in Alaska for the year and (2) present a concise statement of the advancement of the mining industry in the Territory. It affords a means of giving to the mining public the important results of investigations that are underway or completed, pending the appearance of the more elaborate reports, always slow of preparation as well as of publication. Many of the papers contained in this volume have been prepared before the completion of the study of the material collected, and hence the conclusions advanced may not be accepted with the same authority as those contained in the detailed reports to be issued later. Nevertheless, it is believed that these preliminary statements are of value to the prospector and miner, even if they should be regarded only as suggestions.

As in former volumes, the papers here presented fall into three groups—(1) summaries of progress in various phases of the mining industry during the year, (2) preliminary accounts of investigations in progress or completed, and (3) statements of the results of minor investigations not to be published elsewhere.

The attempt is here made to cover the entire field of Alaska mining interests; but to do this it has been necessary to use, in part, information compiled from various sources. It is obviously impossible for the twelve geologists attached to the Alaska division to visit annually all the mining districts in the Territory and at the same time to carry on the more important work of studying the conditions of occurrence and

[a] Report on progress of investigations of mineral resources of Alaska in 1904: Bull. U. S. Geol. Survey No. 259, 1905; idem, 1905: Bull. U. S. Geol. Survey No. 284, 1906.

distribution of the mineral deposits. It has been possible, however, to collect through correspondence considerable information in regard to the status of mining in the districts that were not visited by members of the Survey. The writer would here make acknowledgment to the many Federal officials, mine operators, and prospectors who have cooperated in the collection of these data.

The statistics presented on later pages show that the value of the mineral production in Alaska still comes very largely from the placers. Therefore the description of placer districts—the most important source of the mineral wealth—predominates in this report as in previous volumes. Again, as in previous years, a large part of the investigations and surveys were directed to the mapping of the placer districts of the Yukon and Seward Peninsula, which are the largest producers.

The composite authorship of this volume is evident from the fact that fifteen different papers are presented by eleven different authors. The arrangement of the contributions is, in general, geographic—from south to north. It is unfortunate that the exigencies of prompt publication make it imperative to omit all elaborate illustrations, the reproduction of which necessarily consumes considerable time, and to include only such outline maps and diagrams as can be quickly prepared for printing.

PROGRESS OF SURVEYS.

INTRODUCTION.

In 1906 fourteen parties were engaged in field work during a period varying from two and a half to six months. The technical force of these parties included twelve geologists, four geologic assistants, four topographers, and two hydrographers, in addition to which about thirty camp men were employed. Eight of these parties carried on geologic investigations, two made topographic surveys, three combined both classes of work, and one was employed in stream measurements and hydrographic reconnaissance. The aggregate of the areas covered by geologic reconnaissance surveys during 1906 is 9,000 square miles; by detailed geologic surveys, 548 square miles. Topographic reconnaissance surveys were carried over an area of 10,768 square miles; detailed topographic surveys, over an area of 40 square miles. Detailed hydrographic surveys were made over an area of 200 square miles and reconnaissance surveys over an area of 1,000 square miles. In addition to this, of the 28 Alaskan mining districts in which work is going on, 16, including all but one of the large producers, were visited by members of the Survey. The table on the next page presents a summary of the progress of surveys since the organization of systematic work in 1898.

Progress of surveys in Alaska, 1898–1906.

Year.	Appropriation.	Areas covered (square miles).					
		Reconnaissance geologic.	Detailed geologic.	Reconnaissance topographic.	Detailed topographic.	Reconnaissance hydrographic.	Detailed hydrographic.
1898	$46,189.60	9,500	....	14,912	....	....	....
1899	25,000.00	6,000	....	8,688	....	....	....
1900	25,000.00	10,000	....	11,152	....	....	....
1901	35,000.00	12,000	....	15,664	....	....	....
1902	60,000.00	17,000	....	20,304	336	....	....
1903	60,000.00	13,000	336	15,008	....	....	....
1904	60,000.00	6,000	....	6,480	480	....	....
1905	80,000.00	8,000	550	8,176	948	....	....
1906	80,000.00	9,000	414	10,768	40	1,000	200
	471,189.60	90,500	1,300	111,152	1,804	1,000	200

Although the actual areal surveys are tersely summarized in the above table many of the results can not be presented in this form. For example, practically every mining camp in Alaska has been investigated—some of them in great detail—yet the areal results of this class of surveys are very meager. This will account for the fact that with increased appropriations there has not always been an increase in the areas surveyed. Then, too, in the last three years much of the funds has been spent in detailed surveys, which, to speak roughly, cost ten times as much as the reconnaissance work.

The above table shows that nearly 500,000 [a] square miles in Alaska have not been covered by geologic reconnaissance surveys. Until this work is much more nearly completed all generalizations on the distribution of the mineral wealth must remain largely hypothetical.

Preliminary topographic surveys, including about 50,000 square miles covered by other Government bureaus, have been carried over less than a quarter of the entire area of Alaska. The importance of the rapid extension of such surveys can not be too strongly emphasized, for they furnish not only a guide to the prospector, but are absolutely essential to all engineering enterprises.

It is worthy of note that although nearly half a million dollars has been spent on Alaskan surveys and investigations this is only about one-half of 1 per cent of the value of the gold output from the Territory during the same period.

GEOGRAPHIC DISTRIBUTION OF INVESTIGATIONS.

GENERAL.

As in previous years, much of the time of the geologist in charge was given to administrative duties. The general supervision of the topographic work continued in charge of Mr. Gerdine. During the writer's absence in the field Frank L. Hess looked after the office affairs of the division.

[a] The area of Alaska is 586,400 square miles.

In June, 1906, the writer joined Mr. Kindle at Eagle and together they made a careful study of the geology along the upper Yukon. The main purpose of this work was to gather data which would serve to elucidate the stratigraphic problems, but incidentally some facts were obtained bearing on the occurrence of placer gold and of coal. From Circle the writer went overland to Fairbanks, making an examination on the way of the Birch Creek placer district. A few days were then spent in the Fairbanks district. At the invitation of Maj. W. P. Richardson, the writer joined the party of J. L. McPherson, engineer of the Alaska road commission, and carried a geologic reconnaissance westward from Fairbanks to the rapids on the Yukon, including a brief visit to the Rampart district. The month of September was spent in Seward Peninsula, with the Moffit and Hoyt parties, and in making a study of the Kougarok placer district.

After returning to the office the writer was occupied in preparing a statistical report on the gold and silver production of Alaska in 1905, which has been published in the Mineral Resources of the United States, 1905.

To W. W. Atwood was assigned the task of studying the stratigraphy of the Cretaceous and Tertiary coal-bearing rocks in the Territory, with the purpose of establishing correlation and obtaining information on the relative commercial value of the different fields. The details of this investigation are referred to in another place.

SOUTHEASTERN ALASKA.

The close of the last season witnessed the completion of the preliminary geologic mapping in southeastern Alaska as far northwest as Lituya Bay. There still remains, however, the survey of the Chilkat basin, the inland parts of the larger islands, and the more inaccessible portions of the high ranges. The work of last year embraced an area of about 3,000 or 4,000 square miles, extending northwestward from Lynn Canal to Lituya Bay and including a part of Chichagof Island. This survey was carried on by F. E. and C. W. Wright, assisted by R. W. Pumpelly. Though it was principally geologic some topographic reconnaissance surveys were made and much information was obtained on the retreat of the glaciers in the Glacier Bay region. At the close of the season C. W. Wright visited the Juneau and Ketchikan districts to collect data on the mining progress.

The urgent demand for detailed surveys of the more important mining districts in southeastern Alaska has been met so far as the funds available would permit. In 1906 R. B. Oliver made a survey, on a scale of a mile to the inch, of the more important parts of the Berners Bay district, embracing an area of about 40 square miles.

YAKUTAT-ALSEK REGION.

R. S. Tarr, assisted by B. S. Butler, continued his work in the Yakutat Bay region. He had hoped to cross the Malaspina Glacier to Cape Yaktag, but the fissuring which had taken place in this ice field since his previous visit in 1905 made it utterly impossible to carry out this plan. Mr. Tarr's observations in this region showed that since 1905 an advance of some of the glaciers had taken place. This is, of course, exceptional for Alaskan glaciers, but nevertheless may have an important bearing on the location of railway routes where the fronts of ice sheets have to be traversed.

Eliot Blackwelder, assisted by A. G. Maddren, made a geologic and topographic reconnaissance from Yakutat Bay southward to Alsek River. It was also planned to ascend that stream to the international boundary, but a serious accident prevented the accomplishment of this purpose. A statement of Mr. Blackwelder's results appears on pages 82–88 of this report.

CONTROLLER BAY REGION.

G. C. Martin completed the mapping of the accessible coal and oil fields of the Controller Bay district, begun in 1905. He was assisted by C. E. Weaver, and W. W. Atwood spent about a month in his party. Mr. Martin also carried topographic surveys over an area of about 200 square miles in this region.

COOK INLET REGION.

W. W. Atwood, assisted by C. E. Weaver, studied the stratigraphy of the lignitic coal-bearing rocks on both the east and west shores of Cook Inlet. This was part of the general plan to study the coal-bearing rocks of Alaska, already referred to.

A party under the direction of T. G. Gerdine made a topographic and geologic reconnaissance survey of an area of about 7,200 square miles lying northeast of and adjacent to Cook Inlet. Mr. Gerdine, accompanied by Adolph Knopf as geologist, mapped the valley of Knik River, portions of lower Matanuska River, and the area about its headwaters from Chickaloon Creek northward. R. H. Sargent, topographer, accompanied by Sidney Paige, geologist, mapped the area as far as practicable between Susitna and Matanuska rivers as far north as Chickaloon Creek and Talkeetna River, with an additional small area south of Knik River on the east side of Knik Arm.

At the end of the season Messrs. Gerdine and Sargent completed a traverse of the shore line from Knik southward to the mouth of Kasilof River, and Messrs. Paige and Knopf visited the Cook Inlet placer fields.

SEWARD PENINSULA.

F. H. Moffit, assisted by P. S. Smith, completed the areal mapping of the Nome and Grand Central quadrangles. This work is the first attempt to make an exhaustive study of the geology of any of the placer districts. It is hoped that as a result of such investigations general laws for the occurrence and distribution of the placer gold of the peninsula may be formulated. Mr. Moffit presents a brief abstract of his conclusions on pages 126–145 of this report.

Mr. Smith, in addition to his work with Mr. Moffit, made a reconnaissance of some of the other placer districts of the peninsula,[a] both to gather data on the progress of mining and also to familiarize himself with some of the larger problems of the province.

Most placer mining is directly dependent on a supply of water; therefore a knowledge of the water supply is of first importance to this industry. The accurate determination of the mean discharge of any given stream must be based on observations extending through a long period of years to equalize the variations caused by abnormal seasons. Such an investigation was inaugurated at Nome during the last season. The area investigated embraced a belt of country about 20 miles wide, stretching inland from Nome to the Kigluaik Mountains, a distance of about 40 miles, and was chosen both because of its commercial importance and because the detailed maps were available for calculating the areas of stream basins. It is hoped that funds may be available to continue this work and to extend it to other parts of Alaska.

These hydrographic surveys were made possible only through the cooperation of the water resources branch, which detailed John C. Hoyt, an experienced engineer, to take charge. Mr. Hoyt spent about two months in the field, and the observations were continued by his assistant, F. F. Henshaw. A brief summary of results will be found on pages 182–186. The complete report has already been published.[b]

YUKON DISTRICT.

L. M. Prindle, assisted by C. S. Blair, made a geologic reconnaissance southwest of the lower Tanana, covering about 2,000 square miles. The Kantishna placer district and a part of the Bonnifield, as well as the Cantwell coal field, were embraced within the scope of the investigation.

E. M. Kindle, assisted by V. H. Barnett, made a careful study of the stratigraphy of the Paleozoic rocks of the upper Yukon basin. In the course of this work he ascended Porcupine River as far as the international boundary. This investigation has an important bear-

[a] See pp. 146–163.

[b] Water supply of Nome region, Seward Peninsula, 1906: Water-Sup. and Irr. Paper No. 196, U. S. Geol. Survey.

ing on the correlation of the gold-bearing series of the Yukon-Tanana region.

Topographic reconnaissance surveys were carried westward from Fairbanks to the Yukon and southward to the Tanana by D. C. Witherspoon, assisted by R. B. Oliver. An area of 6,300 square miles was surveyed on a scale of 1:250,000. This completes the preliminary mapping of the Yukon-Tanana region west of the one hundred and forty-fourth meridian except for a narrow belt along the Tanana. In another season it is expected to complete the preliminary mapping of the area lying between Yukon and Tanana rivers and the one hundred and forty-second meridian.

PUBLICATIONS ISSUED IN 1906.

The following Alaska papers and maps were published by the Geological Survey during 1906:

REPORTS INCLUDING MAPS.

BAKER, M., and McCORMICK, J. C., Geographic dictionary of Alaska, second edition: Bull. No. 299, 690 pp. (no maps).

BROOKS, A. H., The geography and geology of Alaska; a summary of existing knowledge, with a section on climate by Cleveland Abbe, jr., and a topographic map and description thereof by R. U. Goode: Prof. Paper No. 45, 327 pp., 34 pls.

BROOKS, A. H., and others, Report on progress of investigations of mineral resources of Alaska in 1905: Bull. No. 284, 169 pp., 14 pls.

COLLIER, A. J., Geology and coal resources of Cape Lisburne region, Alaska: Bull. No. 278, 54 pp., 9 pls.

MARTIN, G. C., Reconnaissance of the Matanuska coal field, Alaska: Bull. No. 289, 36 pp., 5 pls.

MOFFIT, F. H., and STONE, R. W., Mineral resources of the Kenai Peninsula: Gold fields of the Turnagain Arm region (Moffit); Coal fields of the Kachemak Bay region (Stone): Bull. No. 277, 80 pp., 9 pls.

PRINDLE, L. M., Description of the Circle quadrangle (one of a series on the Yukon-Tanana region): Bull. No. 295, 27 pp., 1 pl.

PRINDLE, L. M., and HESS, F. L., The Rampart gold placer region, Alaska: Bull. No. 280, 54 pp., 7 pls.

MAPS PUBLISHED SEPARATELY.

Casadepaga quadrangle, scale 1:62,500.
Grand Central special, scale 1:62,500.
Nome special, scale 1:62,500.
Solomon quadrangle, scale 1:62,500.

REPORTS IN PREPARATION, TO APPEAR IN 1907-8.

The following papers and maps are in various stages of preparation and will be published during 1907 and 1908:

REPORTS INCLUDING MAPS.

BLACKWELDER, ELIOT, Geologic reconnaissance from Yakutat Bay to Alsek River.

BROOKS, A. H., and PRINDLE, L. M., An exploration in the Mount McKinley region (including a description of the Kantishna and Bonnifield districts).

COLLIER, A. J., HESS, F. L., and BROOKS, A. H., The gold placers of a part of the Seward Peninsula.

GRANT, U. S., The geology and mineral resources of Prince William Sound.

HOYT, J. C., and HENSHAW, F. F., Water supply of Nome region, Seward Peninsula, 1906: Water-Sup. and Irr. Paper No. 196.

MARTIN, G. C., Geology and mineral resources of Controller Bay region.

MOFFIT, F. H., HESS, F. L., and SMITH, P. S., The geology and mineral resources of the Nome and Grand Central quadrangles.

PAIGE, SIDNEY, and KNOPF, ADOLPH, Geologic reconnaissance in the Matanuska and Talkeetna basins.

PRINDLE, L. M., Description of the Fairbanks and Rampart quadrangles (one of a series on the Yukon-Tanana region).

SPENCER, A. C., The Juneau gold belt, Alaska; and WRIGHT, C. W., A reconnaissance of Admiralty Island: Bull. No. 287.

TARR, R. S., Geologic reconnaissance in Yakutat Bay region.

WRIGHT, C. W., and WRIGHT, F. E., Mineral resources of the Wrangell and Ketchikan districts.

MAPS TO BE PUBLISHED SEPARATELY.

Berners Bay special, scale 1:62,500.
Controller Bay region special, scale 1:62,500.
Northwestern part of Seward Peninsula, scale 1:250,000.
Northeastern part of Seward Peninsula, scale 1:250,000.
Southern part of Seward Peninsula, scale 1:250,000.

THE MINING INDUSTRY IN 1906.

By Alfred H. Brooks.

FOREWORD.

An increase of nearly 50 per cent in the value of the gold output of 1906 over that of the previous year is the most concrete evidence of the advancement of the mining industry in Alaska. That copper mining, too, has undergone a rapid expansion is manifest by an increase of at least 20 per cent in production over the previous year. Other mineral deposits, such as coal, marble, tin, and gypsum, have also received considerable attention. This progress has consisted chiefly in the development of the older districts rather than in the discoveries of new mineral fields, and can, therefore, be interpreted as an index of continuous advancement rather than abnormal expansion.

Though the placer mines of Nome and Fairbanks were by far the greatest producers of wealth last year, yet they have probably received less attention from investors than the problems of railway construction along the Pacific slope of the Territory. This is another indication of the healthy expansion of the commercial interests and augurs well for a long period of prosperity.

The influx of capital seeking investment in Alaska, so notable during the last few years, continued during 1906. A large number of prominent engineers have been engaged examining prospects and mines, as well as conditions of operating, transportation, etc., in the interests of prospective investors. Unfortunately, with the many legitimate enterprises there is an equal if not greater number of ventures which are promoted with a view of exploiting people ignorant of mining affairs rather than of developing mines. The public can not be too strongly urged to familiarize themselves thoroughly with the plans and assets of companies that invite popular subscription. Many honest promoters, because of their inexperience in mining affairs, mislead their equally inexperienced stockholders. Every such venture which fails retards the advancement of the mining interests by making investors suspicious of all other enterprises in the district.

STATISTICS.

The collection of accurate statistics of mineral production, a task much beset with difficulties even in well-settled regions, is in Alaska, with its indifferent mail facilities, as yet well-nigh hopeless. Up to 1905 no systematic attempt was made by the Geological Survey to gather statistics at first hand, the work being limited to distributing among the different districts, according to the best information available, the totals as published by the Director of the Mint. The first attempt to gather this kind of information was confined to estimates furnished by residents of the Territory and in many cases checked by the personal observations of the geologists working in various fields. By 1906 the improvement of the mail facilities and general accessibility of the country was deemed to have gone far enough to warrant an attempt to obtain statistics through schedules sent to the individual producers. This experiment was, however, only partially successful. Though nearly all the lode miners throughout the Territory have been prompt to reply and to send the desired information, the returns received from placer miners were very disappointing. Most of the small operators in the less important districts have, indeed, shown their willingness to cooperate in this statistical work by furnishing the desired information, but on the other hand the majority of the large operators, especially in the Nome region, have either ignored the request for information entirely or have returned the schedule without furnishing any information as to production. This seems particularly unjust, because it is the large operators who have benefited most by the work of the Geological Survey, and it seems as if they should have shown their good will by acceding to the request for information. In undertaking this work the writer believed that the mine operators would be the first to recognize its importance and would, therefore, be willing to cooperate. It has been a source of deep disappointment to him that such has not proved to be the case. While it may appear at first thought that by replying to the questions asked on the circular an operator is revealing information which might be used to his disadvantage, yet this fear is groundless, because the schedules are used only to make up totals of districts and all individual productions are held in strict confidence. It is the earnest hope of the writer that in the future mine operators may further the collection of reliable statistics and show their confidence in the Geological Survey by furnishing the desired information.

The following table of gold production is based on the best information available. The totals since 1898 are probably correct within 5 or 10 per cent, but the error in distribution of these totals among the various districts is probably much greater.

Value of gold production of Alaska, with approximate distribution, 1880–1906.

Year.	Pacific coastal belt.	Copper River and Cook Inlet region.	Yukon basin.	Seward Peninsula.	Total.
1880	$20,000				$20,000
1881	40,000				40,000
1882	150,000				150,000
1883	300,000		$1,000		301,000
1884	200,000		1,000		201,000
1885	275,000		25,000		300,000
1886	416,000		30,000		446,000
1887	645,000		30,000		675,000
1888	815,000		35,000		850,000
1889	860,000		40,000		900,000
1890	712,000		50,000		762,000
1891	800,000		100,000		900,000
1892	970,000		110,000		1,080,000
1893	833,000		200,000		1,038,000
1894	882,000		400,000		1,282,000
1895	1,569,500	$50,000	709,000		2,328,500
1896	1,941,000	120,000	800,000		2,861,000
1897	1,799,500	175,000	450,000	$15,000	2,439,500
1898	1,892,000	150,000	400,000	75,000	2,517,000
1899	2,152,000	150,000	500,000	2,800,000	5,602,000
1900	2,606,000	160,000	650,000	4,750,000	8,166,000
1901	2,072,000	180,000	550,000	4,130,700	6,932,700
1902	2,546,600	375,000	800,000	4,561,800	8,283,400
1903	2,843,000	375,000	1,000,000	4,465,600	8,683,600
1904	3,195,800	500,000	1,300,000	4,164,600	9,160,000
1905	3,430,000	500,000	6,900,000	4,800,000	15,630,000
1906 [a]	3,500,000	400,000	10,400,000	7,500,000	21,800,000
	37,465,400	3,135,000	25,481,000	37,262,700	103,348,700

[a] Preliminary estimates.

The silver production of 1906 is estimated to have been about 170,000 ounces, compared with 132,000 ounces in 1905. In 1906 the copper production is estimated to have been somewhat over 7,600,000 pounds, compared with 4,800,000 pounds in 1905. The output of other mineral products will be discussed in succeeding pages.

Estimated value of Alaska's mineral production in 1906.

Gold	$21,800,000
Silver	120,000
Copper	1,200,000
Coal	20,000
Miscellaneous, including tin, marble, etc	10,000
	23,150,000

TRANSPORTATION.

Transportation problems are still in the forefront throughout Alaska. Steamboat service, both on the rivers and oceans, is being rapidly improved, but with the exception of a few short railways overland transportation is still very primitive.

In Seward Peninsula two railways, referred to elsewhere (pp. 144, 153), have been extended, giving a total length of about 100 miles. In the Yukon region the railway from Fairbanks to Pedro Creek is doing a noteworthy service to the mining interests, but needs to be extended. On the Gulf of Alaska two railways are being constructed, one from Resurrection Bay and one from Cordova Bay, and other projects are

being earnestly considered. The railway situation, as regards inland extensions, leaves much to be desired, as the various interests are in many cases antagonistic. Current reports indicate that two important projects for a railway to the copper fields of the Chitina and the Controller Bay coal field are to be merged, which will assure early connection with these important mineral districts. Year by year the demand for railway connection of the inland region with open water on the Pacific becomes more imperative. Until such lines of communication are established, the development, if any, attainable by the interior districts will be very slight.

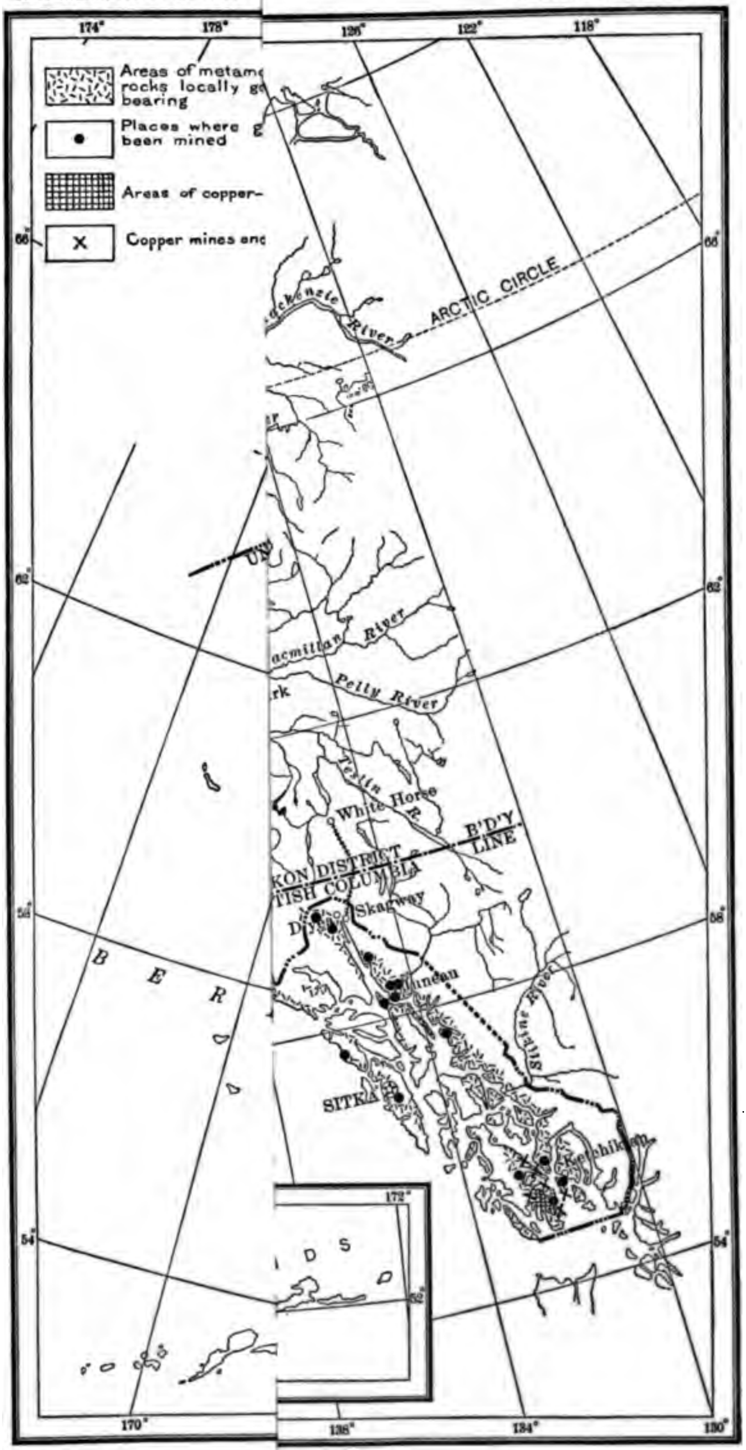
The Alaskan road commission, under the direction of Maj. W. P. Richardson, is doing much to help the mining interests in various parts of the Territory by highway and trail construction. As there is no form of local government outside of incorporated towns, the miner is entirely dependent on the Federal Government for the advancement of road construction, and it is to be hoped that the road commission may have sufficient funds to meet the many worthy demands for highways.

DISTRIBUTION OF PRECIOUS METALS.

It is the ultimate purpose of the geologic investigations carried on in Alaska to determine the laws governing the occurrence and distribution of the precious metals. Such a determination, however, must await far more detailed and comprehensive studies than have yet been accomplished. Meanwhile, with the progress of this work, there is an accumulation of evidence which suggests certain conclusions not yet susceptible of proof. As these may serve as a guide to the prospector, it will be desirable to set them forth briefly.

It has long been demonstrated that ore bodies, as a rule, occur in rocks which have been subjected to more or less alteration, or metamorphism, as it is usually called. Such metamorphism may be regional—that is, it may have been brought about by stresses in the earth's crust which have affected large areas—or it may be due to local disturbances, many of which are caused by intrusive masses. It is also possible that both regional and local metamorphism have affected the same formation. It should be noted that where there is any considerable metamorphism, both chemical and physical changes usually take place, as for example in the alteration of shale to schist or of granite to schist. These rock changes are important to the miner because, by increasing permeability, etc., they affect the occurrence of ore bodies, and necessarily the derived placers.

On the accompanying map (Pl. I) the distribution of the metamorphic rocks is indicated so far as they are known. These areas indicated as metamorphic have thus far been the wealth producers, as


Areas of metamc
rocks locally g
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been mined
Areas of copper-
Copper mines anc
ARCTIC CIRCLE
Mackenzie River
Macmillan River
Pelly River
Teslin R.
White Horse
B'D'Y LINE
YUKON DISTRICT
BRITISH COLUMBIA
Skagway
Dyea
Juneau
SITKA
Ketchikan
Stikine River
B E R
D S
174°
178°
126°
122°
118°
66°
62°
58°
54°
170°
138°
134°
130°
172°
52°

KNOWN.

they contain over 99 per cent of all the gold mines in the Territory. It does not follow, however, that there are no precious metals outside of the metamorphic areas. For example, the Apollo mine on Unga Island, in southwestern Alaska, is in a series of comparatively recent lava flows which have been altered only very locally. Again, some of the Tertiary conglomerates in the Yukon basin are known to be auriferous, but it should be said that in this case the gold was undoubtedly derived from the metamorphic terranes. These exceptions to the general law are of importance because they show that other formations than those indicated as metamorphic may contain precious metals.

The map clearly shows that there are three general zones of metamorphic rocks in Alaska. One skirts the Pacific seaboard, stretches through southeastern Alaska, and appears to occur again on lower Copper River, on Kenai Peninsula, and on Kodiak Island. It is not to be inferred that this belt is made up entirely of formations of the same age, though such may prove to be the case. The map is intended simply to express the fact that in this belt there are considerable areas of metamorphic rocks. In southeastern Alaska these altered rocks belong to Paleozoic terranes, but to the west no definite age determination has been made.

A second and much larger belt of metamorphic rock lies to the north and west of the coastal zone, stretching from the international boundary through the Yukon and Tanana region, and appears to trend to the southwest, paralleling like the first the larger structural features of the Territory. This belt is broken near Yukon River by younger beds, but appears again in Seward Peninsula. A third belt, whose relation to the second has not been established, as the intervening areas are occupied by younger sediments, stretches through the upper Koyukuk Valley and is found again on the Kobuk. Though the map suggests that the easterly extension of this third zone should be found in the Porcupine Valley, yet the work of E. M. Kindle has shown that while the same rocks are probably present near the point where the international boundary crosses the Porcupine, they are there not altered. This emphasizes the well-known fact that although a group of terranes may be highly altered in one locality, its extension may be made up of slightly altered rocks. The prospector should bear this fact in mind in seeking for new mining fields. So far as the evidence goes, the Porcupine basin does not seem a promising field for gold discoveries. On the other hand, the metamorphic rocks of Seward Peninsula probably find an extension east of the locality where they are indicated on the map. The metamorphic rocks of the inland zones are probably chiefly of Paleozoic age. Between the two general zones of metamorphic terranes there are some smaller belts of

highly altered rocks which locally have proved to be gold bearing. It is presumable that some of these will be found to cover larger areas than here indicated.

The experienced prospector need not be told that it does not follow that because a certain formation is gold bearing gold will be found wherever it occurs. A tyro, however, may interpret the accompanying map as an absolute indication of the distribution of gold rather than as a guide to localities where the precious metal is likely to be found. Although the laws governing the distribution of gold in this field are but imperfectly understood, it seems certain that the occurrence of mineralization is due to causes that have in many places acted very locally. There appear to be no facts which bear out the assumption often made that there are one or more well-defined gold belts which can be traced across Alaska, though the formations with which gold is associated may be found to be continuous over extensive areas. The work so far accomplished appears to justify the statement that within the areas of metamorphic rocks there are zones of mineralization. These are, however, usually of very slight extent, ranging from only a few hundred yards to rarely a few miles in length. There is but little information on which to formulate a law for the occurrence of these mineral zones, and it is quite possible that in the different districts different causes have been operative.

It appears to have been definitely established by Mr. Wright (see pp. 49–50) that in southeastern Alaska there is a causal relation between the intrusion of the Mesozoic granites and the ore bodies. As he sets forth, the zones of mineralization thus far discovered all occur along or near the margins of the intrusive granite masses. There is some evidence that a similar association of the zones of mineralization and the granite exists in the Yukon district. Prindle has shown that granitic rocks are common in all the gold-placer districts of the Yukon-Tanana region and that in at least one locality the gold is closely associated with intrusive phenomena. He has also suggested that intrusion and the formation of quartz veins took place at different periods.[a] During the last summer the writer found evidence of mineralization accompanied by deposition of gold in the so-called Aucella beds (lower Cretaceous) on Washington Creek, a tributary of the Yukon. This appears to be the first instance in this province where definite proof was obtained of a post-Paleozoic mineralization, and is significant because it appears to belong to the same period as the intrusion of auriferous veins in southeastern Alaska.

Mendenhall[b] has shown that in the Chistochina placer district of upper Copper River the mineralization is post-Permian and pre-Eocene,

[a] Prindle, L. M., The gold placers of the Fortymile, Birch Creek, and Fairbanks regions, Alaska: Bull. U. S. Geol. Survey No. 251, 1905, p. 37.

[b] Mendenhall, W. C., Geology of the central Copper River region: Prof. Paper U. S. Geol. Survey No. 41, 1905, p. 115.

so that it may be correlated with that on Washington Creek. Moreover, his geologic map shows the gold-bearing area to be intruded by many igneous rocks which are of the same general composition as the granites of southeastern Alaska. In other words, this occurrence appears to be closely analogous to the gold deposits of southeastern Alaska. Furthermore, some evidence is at hand which suggests a similar origin for the gold of the Susitna basin.

It is safe, therefore, to assert that the intrusion of the Mesozoic granite in many parts of Alaska was accompanied or followed by the formation of auriferous veins. It is important, therefore, to draw attention to the distribution of this rock. As shown by Mr. Wright, it not only forms the major portion of the Coast Range, but also finds a wide distribution in isolated stocks among the islands to the west. The main granite mass passes into Canadian territory in the Chilkat basin and has been traced northward to Kluane Lake, where, too, evidence of mineralization is found. It occurs again in the form of dikes and stocks along the northern margin of the Copper River valley and has been recognized at a number of places in the Alaska Range to the southwest.

The genetic relation of the auriferous deposits of Seward Peninsula is still an unsolved problem, but so far no connection with the granitic intrusions has been established. Mr. Moffit shows elsewhere in this report (see pp. 130–132) that the placer gold of the Nome region proper finds its source in a series of closely folded and faulted metamorphic rocks and apparently most commonly along the contact between the schists and crystalline limestones. The only ore deposits in this province which have been found in association with granite intrusions are the cassiterite lodes, which, as Collier[a] and Hess[b] have shown, are closely connected with the intrusions. The developments of the past year at Cape Mountain clearly show that the tin ores occur along the margins of the granite. It is unfortunate that little is known of the age of this granite. While it has generally been regarded as Paleozoic, it may be Mesozoic, but is certainly pre-Eocene.

The matter already presented refers chiefly to the auriferous veins, but is probably applicable to some of the copper deposits, especially in southeastern Alaska. In Prince William Sound[c] the copper deposits are intimately associated with greenstones and greenstone schists, probably of Mesozoic age, which are relatively little altered. Granite intrusions are present in this province, but the ore bodies are not known to have any genetic relation to them. The copper ores of Copper River occur as contact deposits along a semicrystalline lime-

[a] Collier, A. J., Tin deposits of the York region, Alaska: Bull. U. S. Geol. Survey No. 229, 1904; Recent development of Alaskan tin deposits: Bull. U. S. Geol. Survey No. 259, 1905, pp. 120-127.

[b] Hess, F. L., The York tin region: Bull. U. S. Geol. Survey No. 284, 1906, pp. 145-157.

[c] Grant, U. S., Copper and other mineral resources of Prince William Sound: Bull. U. S. Geol. Survey No. 284, 1906, pp. 78-87.

stone and a greenstone which is probably an ancient lava flow.[a] The foregoing statements indicate that some of the copper-bearing lodes of Alaska appear, in part, at least, to be the result of a different group of phenomena from those which caused the auriferous lodes.

LODE MINING.

INTRODUCTION.

The most notable advance in lode mining during 1906 was the development of the copper deposits of the Ketchikan district and of Prince William Sound. While steady progress has been made in the auriferous mines of the Juneau district there were no marked developments. Statistics are not yet available, but it is not probable that the output of gold from this district was notably greater than in 1905, nor have any important discoveries of new auriferous-lode districts been reported. In Seward Peninsula the one developed lode mine has continued to be a producer and there was a noteworthy activity in prospecting quartz veins, but here also no important discoveries have been reported. Statements are current that auriferous copper-bearing lodes have been found in the Kobuk Valley and in the Susitna basin, but the proof of their commercial value will have to await further investigations. The same holds true of the auriferous lodes reported from Kenai Peninsula and Kodiak and adjacent islands. The copper-bearing property in the Iliamna Lake region has received some attention, but the writer has scanty information regarding it. It is at least of interest in suggesting the occurrence of mineralization in this little-known field. Though auriferous veins have been found in the Yukon basin, nothing of commercial importance has so far been developed.

STATISTICS.

It is unfortunate that the statistical data are not all in hand yet and that therefore the production can be stated only in general terms. It is probable that the value of the gold production from siliceous ores for 1906 is about $3,450,000 and that the copper ores yielded about $100,000 in gold. The value of the silver from both classes of ore for 1906 is probably about $50,000. The copper production of 1906 is estimated to have been about 6,000,000 pounds, valued at about $1,100,000. It is estimated that thirteen gold and silver mines were on a productive basis in 1906, as compared with ten in 1905. Fourteen copper mines are believed to have been operated in 1906, as compared with eight in 1905. In addition to the productive mines many prospects were being developed, especially in the copper districts. It has been impossible to gather any complete data in regard to the

[a] Mendenhall, W. C., and Schrader, F. C., Mineral resources of the Wrangell region: Prof. Paper U. S. Geol. Survey No. 15, 1903.

number of placer mines, but it is fair to presume that they include at least 1,200 different operations. In the absence of accurate information about tonnage and values for 1906 it seems worth while to make the following quotation in relation to the production of 1905:

> The tonnage of all the lode mines of Alaska in 1905 was 1,422,515 short tons, an increase of probably about 40,000 tons over 1904. Of siliceous ores 1,370,316 tons were mined, of which 1,296,271 tons must be credited to the three mines of the Treadwell group on Douglas Island, near Juneau, leaving only 74,045 tons as the product of the other gold-quartz mines. The average gold and silver value of all siliceous ores was $2.63 per ton. For the 74,045 tons of siliceous ores other than those from the Treadwell group it was $5.60. A total of 52,199 tons of copper ores contained an average of $1.66 per ton of gold and silver, and copper to the amount of 4.61 per cent. It should be stated that the values of the siliceous ores mined thus far lie almost altogether in the gold, the silver values being often less than 1 per cent of the total. The high percentage of copper is accounted for by the fact that the Prince William Sound mines, which contributed a large percentage of the total tonnage in 1905, have so far shipped only high-grade ores. The copper percentage of ores from the Prince William Sound mines is nearly twice that of ores from the mines of southeastern Alaska.[a]

It can be added that the tonnage and values in the siliceous ore were probably about the same in 1906 as in 1905. The copper ores in 1906, however, showed an increase of at least 20 per cent, but the values remained about the same.

LODE DISTRICTS.

The southeastern Alaska districts are fully treated in other pages of this report. Prince William Sound and Copper River were not visited by any member of the Survey and the following notes are compiled from various sources.

The copper mines and prospects of Prince William Sound thus far discovered all fall within a zone about 10 to 20 miles in width stretching northeastward from Latouche Island to Boulder and Galena bays on the mainland. An examination of the map (Pl. I, p. 22) shows that much of this zone is under the water of the sound. As Grant[b] has shown, the ore bodies, chiefly chalcopyrite, occur as a rule along shear zones in the greenstone.

Two mines, the Gladhaugh and Bonanza, made shipments of ore to the Tacoma smelter throughout the year, and several other properties undergoing development also made some production. In the Gladhaugh mine a sixth level at 600 feet depth is said to have been reached. Though only a few properties have reached a shipping stage, there are probably two score that have been prospected during the past year. Most of this work was done on Latouche and Knight islands and at Boulder, Landlocked, and Galena bays. It is estimated that from 100 to 200 men have been almost continuously

[a] Brooks, Alfred H., Mineral resources U. S. for 1905, U. S. Geol. Survey, 1906, p. 129.

[b] Grant, U. S., Copper and other mineral resources of Prince William Sound: Bull. U. S. Geol. Survey, No. 284, 1906, pp. 78-87.

employed in these operations. It seems probable that in 1907 the number of productive mines will be very much increased.

The two copper belts on the north and south sides of the Wrangell Mountains continue to be a field of much prospecting. Developments have been confined chiefly to the more accessible southern belt, which it is expected will be connected by railway with tide water in the next two years. This mineral belt has been carefully traced by prospectors and probably most of it has been preempted by this time. On most of these claims, however, assessment work alone has been done. There has been systematic development on a number of larger holdings, notably on the Hubbard-Elliot property near the west end of the range, and on the Bonanza near the east end. It is claimed that a depth of 200 feet has been reached on the Bonanza.

In the upper copper belt, stretching more or less brokenly from White River to the head of Tanana and Copper rivers, a score or more prospectors have been at work and several new discoveries are reported. Some of them are so close to the international boundary that until an accurate delineation of that line is made it will be uncertain on which side of it they lie. It is reported that native copper-bearing lodes have been found on Kletsan Creek and on Camp Creek. The other copper deposits of this region are chiefly sulphides.

The most important fact in regard to the development of these copper districts is the assurance of a railway from the coast. Although the location of the coastal terminal, if current reports are to be credited, is not yet definitely settled, it probably will be either Cordova Bay or Katalla, from which a railway will be extended up Copper River. Meanwhile steps have been taken to establish means of communication by small steamers which will run between the rapids of Copper River and will be provisionally connected by tramways.

YORK TIN REGION.

No member of the Geological Survey visited the tin district during 1906. Current reports indicate considerable progress in lode mining at Cape Mountain and prospecting at Lost River and at Brooks and Ear mountains. The Buck Creek tin placers also received attention, and some shipments of stream tin were made.

The margin of the granite mass of Cape Mountain, which appears to be the locus of the tin-bearing lodes, has been traced and entirely covered by locations, and considerable prospecting has also been done. During the last year cassiterite-bearing veins were found on the northwest side of the mountain, in the basin of Village Creek. The prospects are reported to be encouraging and at least are known to have the same general character as the better developed deposits on the southeast side of the mountain. By far the most extensive

operations of the district are those of the Bartels Tin Mining Company, on the southern slope of Cape Mountain. This company installed a 3-stamp mill in 1905, and some concentrates were shipped during the year. Current reports, which the writer is unable to verify, indicate that the ledge varies in thickness from 18 inches to several feet. Values of 1 to 55 per cent are reported, and the average of the ore mined is said to have been 3¾ per cent. The company is mining and also prospecting systematically with electric-power drills. An enlargement of the plant is said to be in contemplation. The United States-Alaska Tin Mining Company has erected a 10-stamp mill in the same region, but no shipments are reported. The Seward Tin Mining Company is said to be at work in the same vicinity, and some prospecting is reported on the Compass, Bear, Midnight, and Sun claims. The developments on the north side of Cape Mountain, at Village Creek, have already been referred to.

Less definite information is available concerning the operations at Ear Mountain and Lost River, but current reports indicate that systematic prospecting is still going on. The Lost River deposits are near the coast, but the Ear Mountain district is less accessible.

As no further studies have been made, it is impossible to present any conclusions in regard to the future of the district beyond those already advanced by Collier [a] and Hess.[b] The actual shipment of ore and the continuation of work in the various localities bear testimony of progress. There can be no doubt that this district has suffered by the exaggerated estimates of the tonnage of ore developed and its value, which have been published far and wide. While these are in part to be credited to conscienceless promoters, who are using tin prospects as a basis for the selling of stock, it is also due to the ignorance of honest prospectors. Nearly all the owners of tin prospects hold them at such enormous figures that the experts sent to examine them often must advise their clients against purchase. Those who are inexperienced in lode mining, especially of tin ores, should understand that capitalists will not pay for a prospect the same amount of money which they would for a developed mine. Had this fact been accepted by the prospectors, much more prospecting would no doubt by this time be carried on in this field by the moneyed interests.

In 1905 the average price of tin was 31.35 cents per pound; in 1906 it rose to 39.81 cents per pound. The world's production of tin in 1906 was 93,919 long tons, or about 500 tons less than in 1905. Of the total production about 47 per cent was used in the United States, with practically no production. These facts alone assure a continuation of the search for tin, especially in a field which has yielded as encouraging results as the York district.

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[a] Collier, Arthur J., Tin deposits of the York region, Alaska: Bull. U. S. Geol. Survey No. 229, 1904.

[b] Hess, Frank L., The York tin region: Bull. U. S. Geol. Survey No. 284, 1906, pp. 145-157.

ANTIMONY.

Stibnite, the sulphide of antimony, has been found at a number of widely separated localities in Alaska, and in view of the constantly increasing demand for antimony it has seemed worth while to call the attention of prospectors to it. In 1906 the price of the metallic antimony increased from 14 and 15 cents to 25 and 26 cents a pound. The consumption of antimony in 1905 for the United States was 5,712 short tons, with no production except some recovered with lead ores. This fact has stimulated the search for commercial ore bodies containing the metal. Antimony finds its principal use in the manufacture of various alloys and in some chemical compounds.

Stibnite is a soft mineral, of a lead or steel-gray color, having a streak of similar color usually with a more or less perfect cleavage visible to the naked eye. This mineral is usually found in veins having a quartz gangue and associated with various other metals. The ore often contains some gold and silver. Of the valuation of the ores Schnatterbeck[a] makes the following statement:

> For the information of miners it may be said that smelters pay for ore according to its content of antimony (determined by a fire assay) and its freedom from impurities, such as arsenic, lead, and copper. Ores carrying less than 50 per cent metal are not marketable at present unless they have other unique features which would facilitate smelting. The smelter usually deducts about 30 cents per ton for sampling and weighing ore. In calculating the value of an ore the basis of quotations for metal in London is used, and should the ore exceed 50 per cent metal a premium is allowed, while for every per cent less a discount is exacted.

No ore bodies containing stibnite of proved economic importance have been found in Alaska. The ore is, however, known to occur at the localities mentioned in the following paragraphs:

Antimony ores have been reported from various localities in Seward Peninsula, but the only occurrence known to the writer is on Manila Creek and is described elsewhere in this report (p. 139).

Mr. Prindle reports the occurrence of stibnite in the placers of Cleary and Esther creeks, and he found it in place on Chatham Creek. At the latter locality[b] a vein a foot or more in thickness occurs in the schists.

In the Kantishna region Mr. Prindle found stibnite associated with the auriferous gravels on Eureka and Friday creeks, and in place on Caribou Creek. (See pp. 216, 219.)

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[a] Schnatterbeck, C. C., The production of antimony in 1905: Mineral Resources U. S. for 1905, U. S. Geol. Survey, 1906, p. 437.

[b] Bull. U. S. Geol. Survey No. 284, 1906, p. 114.

PLACER MINING.

INTRODUCTION.

Of the $21,600,000 worth of gold produced in Alaska in 1906, nearly $18,000,000 came from the placers, and more than half of this from the Fairbanks district. Seward Peninsula stands second, with a production of over $7,500,000, of which at least one-half came from the old beach line. The silver recovered from the placer gold represented in 1906 about two-thirds of the total output of that metal in Alaska, and had a value of about $60,000.

No new placer districts were discovered in 1906, but the Yentna, Kantishna, and Tenderfoot have become producers since last year. Mining in both Seward Peninsula and the Yukon district was more or less handicapped by the scarcity of water during a part of the open season.

METHODS.

The evolution of placer-mining methods, which is going on continuously, is directed chiefly toward the introduction of machinery in some form. As districts become more accessible the small operator is supplanted by companies with ample financial backing, to bring about a reduction of costs of operation. Moreover, the wasteful methods of the pioneer prospector can find no reward except in the richest and most favorably situated placers, and the gravels of lower value must await better capitalized companies. This change is taking place throughout Alaska, but notably in the Nome region. The most significant feature of this evolution during the last year was the systematic search for placer ground suitable for dredging.

Much has been written on the subject of dredging and its possible application as a mining method in this northern region. Though this is a matter for discussion by the mining engineer rather than by the geologist, a brief statement of a few conditions affecting dredging in this field may be of service to those who are not personally familiar with them. On the one hand, prominent mining engineers have been loud in proclaiming the inapplicability of dredging throughout most of Alaska because of the failure of certain misdirected efforts; on the other, less conscientious promotors have cited the low values profitably recovered by dredging in the Oroville (Cal.) and similar fields as examples of what may be accomplished in Alaska.

From the standpoint of dredging, the Territory may be divided into two provinces, one embracing the area tributary to the Pacific, and the other the placer districts of the Yukon and Seward Peninsula. In the Pacific province there are a number of placer districts which undoubtedly include some good dredging ground, yet in this part of Alaska glacial bowlders are not uncommon. Even in glaciated areas, where only easily decomposed rocks, such as mica schist, are present,

large bowlders may be exceptional. In general, however, bowlders must be expected, since glaciation has been an active agent throughout this province. As a rule the placers of this part of Alaska have not been found to be as rich as those of the Yukon and Seward Peninsula. On the other hand, frost is not encountered in the region tributary to the Pacific except in the Copper River basin and possibly in the upper basin of the Susitna. Other and very important factors in favor of the southern province are its accessibility, relatively cheap fuel, and abundance of water power. In the Yukon and Seward Peninsula districts glaciation is, for the most part, absent and bowlders are relatively rare. The values also average much higher, though these vary, of course, locally. Of fundamental importance for consideration in these fields is the large amount of frozen ground which can not be handled by a dredge unless previously thawed. The laws which govern the distribution of the ground ice are not known, so that each placer must be carefully tested on this point before a decision is reached. In general, however, it can be stated as an established fact that the river beds are not frozen, and also that any loose sand or gravel which is well drained is not frozen. The cost of fuel, transportation, and other factors which have been mentioned, vary in different districts of this northern province, but in general are higher than along the Pacific coast. Water power, too, is much rarer than in the southern field. In a comparison of the two provinces it is obvious that the southern field is one where bowlders are to be expected, while in the north the presence of frozen ground may so increase the cost of exploitation as to make it prohibitive.

It may be of value to present some facts on the costs and methods of dredging frozen ground, as determined in the Klondike. The writer is indebted to Mr. Albert J. Beaudette, government mining engineer of the Yukon Territory, for the following statement:

The dredge now operating on Bonanza Creek was erected on creek claim No. 42 below Discovery in the year 1901 and afterwards removed to where it is now, on Discovery claim, a distance of about 4 miles farther upstream. It is one of the old type of dredges manufactured in San Francisco, using steam as its motive power. This boat has a theoretical capacity of 1,200 cubic yards per twenty-four hours, but this year it has excavated on an average 700 cubic yards per twenty-four hours for a period of one hundred and twenty-seven days. The capacity of the buckets is 3¼ cubic feet, moving with a velocity of 14 to 16 buckets a minute. It requires 65 horsepower to run the dredge.

The great drawback in dredging operations is the "frost," which must be overcome at any cost before the gravel can be excavated and washed. As the plant on the dredge is too small to furnish steam for both the dredge and the points used for thawing, the management had to erect another plant near by to furnish steam for the points. This plant consists of two boilers of 50 horsepower each, 60 points, and pipes to transmit the steam from the boilers to the points at a distance of 25 to 100 feet from the boilers. The points used are from 14 to 16 feet in length and they will thaw the material to the bed rock.

The claims upon which the dredge is being operated have all been worked by the placer method, and it has been found that a great portion of the ground is already thawed and only places where the muck has not been removed are required to be thawed by steam. In the spring the thawing begins fully a month before the dredge is put into operation, and in that way there is always enough ground thawed ahead of the dredge to keep it in operation. The ground is 15 feet to bed rock, consisting nowhere of more than 4 feet of muck and the remainder gravel. The character of the bed rock changes many times in one cross section of the creek from very soft to very hard and slabby, which will affect the duty of the point. The amount of ground that can be thawed by each point varies from 5 to 8 cubic yards in twenty-four hours, according to the amount of muck and the depth to bed rock, the lowest average being 3 feet square of bed rock for a depth of 15 feet to each point.

I here give you concise data about the operations, together with the costs:

Wood used per twenty-four hours....cords..	5½
Cost of wood per cord....	$13.50
Labor, 2 shifts, 3 men each shift....	$40.00
Cubic yards thawed per twenty-four hours....	400
Cost per cubic yard for thawing....cents..	28.5

The above is the expenditure for thawing alone, for which the plant cost about $4,000.

The figures above given are in a general way applicable to the inland placer districts of Alaska. Costs will, of course, vary according to locality. On Seward Peninsula the operating expenses, as well as the cost of installment of the plant, should be less than these figures.

The question of water supply for hydraulic-mining purposes is still of supreme importance in all the placer districts. At Nome and in other parts of Seward Peninsula the rapid extension of ditches will very soon drain all the streams available for use in hydraulic mining, and then placer-mining operations will cease to expand in this direction. With the cheaper fuel which is likely to come with the utilizing of water powers, other than hydraulic methods will undoubtedly be introduced. In the Yukon camps but little ditch building has taken place, and most of the mining work has been in rich ground, where hydraulic methods are not necessary for profitable exploitation. The deep-lying gravels of the Fairbanks district must always be mined by underground methods, and the only hope of material reduction in costs appears to be in lessening the expense of transportation.

PLACER MINING, BY DISTRICTS.

It is here proposed to summarize the mining developments in the regions which are not more fully treated in other parts of the report. As the following notes are only in part based on the observations of members of the Geological Survey, they must of necessity be ill balanced.

PACIFIC COAST REGION.

Mr. Wright treats of the placers of the Juneau, Porcupine, and Lituya Bay districts in this report (pp. 51, 55, 56, 64, 65). The most noteworthy fact is the small advance made in placer mining in the Porcupine field. An abundance of water and steep gradients, with considerable bodies of gravel, are the favorable conditions in this field, but, on the other hand, the district is handicapped by the ruggedness of the topography and the frequent floods, which often carry away the miners' equipment. The presence of glacial bowlders over much of this district is unfavorable to dredging operations. Although the values average much lower than in the Yukon and Seward placers, yet they are within the limits of profitable mining, provided the other difficulties can be overcome.

The beach placers at various places along the seaboard between Lituya Bay and Unga Island yield only a small annual production, but probably give employment every year to half a hundred men. These deposits are of such a character that they can not be mined on any but a small scale. All attempts so far made to exploit them with machinery have met with failure. Yaktag Beach, which is about 60 miles east of Controller Bay, is estimated to have produced about $25,000 in 1906. About $10,000 worth of gold has been taken from the beaches of Kodiak and the other islands lying to the southwest.

In the Copper River region the most active placer-mining operations were in the Nizina basin, tributary to the Chitina. This district lies about 200 miles by trail from tide water, and the cost of operations is necessarily very high. It is reported that five claims were operated in the summer of 1906, employing in the aggregate 30 men. In the Chistochina district no rapid progress is reported, but considerable mining was carried on.

The Cook Inlet placers are described elsewhere (pp. 115–124), and it is shown that there has been a decided falling off in output as compared with 1905. The one important advancement is the exploitation of the placers of the Yentna district. The value of the production for 1906 of Cook Inlet and Copper River is estimated to have been $400,000.

SEWARD PENINSULA.

The Nome district continues to be the mining center of Seward Peninsula, with the Council district as second. Of the production of $7,500,000 for the entire peninsula, probably 50 per cent must be credited to the third-beach placers near Nome. These two important districts, as well as the Kougarok, are described elsewhere in this report (pp. 126–181). In the lesser districts, such as the Bluestone

and Teller, some developments are being made, but they are entirely overshadowed by the other camps.

In the Fairhaven precinct notable advancements were made, chiefly in ditch building. The Fairhaven Water Company completed the construction of about 30 miles of ditch, which taps Imuruk Lake and which when completed will have a total length of 52 miles and will discharge at Washington Gulch, an easterly tributary of the Inmachuk. The ditch has a capacity of 5,700 miner's inches. A 4-mile ditch is being built at Hannum Creek. A number of surveys have been made, with a view of bringing water to Candle Creek, where the rich bench placers are being worked.

Dry weather prevailed in the Fairhaven district, as in other parts of of the peninsula, and hence the largest production was made during the winter months. Considerable gold was taken out of the benches of Candle Creek by winter drifting. The coal mine at Chicago Creek furnishes the fuel for these undertakings. Some rich placer ground was mined on Chicago Creek, and current reports indicate that one claim at this locality was the largest producer of the season. It is also stated on good authority that prospecting in the immediate vicinity of the ground failed to reveal any other workable deposits. Considerable winter work was done on the lower Inmachuk and its tributaries. It seems probable that the value of the production of this camp in 1906 was between $200,000 and $300,000, though by some it is stated as high as $500,000.

YUKON BASIN.

The enormous production of the Fairbanks district, which amounted to over $9,000,000, overshadowed all other developments in the Yukon basin. The smaller districts all made progress during the year. Of these the most accessible, such as the Rampart, and to a certain degree Birch Creek, naturally received the most attention.

FAIRBANKS.

It is estimated that between 5,000 and 6,000, people were in the Fairbanks district during the summer of 1906. Probably over 50 per cent of these left before the fall freeze-up. A large part of the influx was made up of people with little money or experience in mining, and naturally the expectations of many were doomed to disappointment.

In spite of the prosperous condition, the midsummer saw the camp crowded with men who could find nothing to do. While wages continued high, $5 to $6 a day with board, the character of most of the operations made it possible to employ but few inexperienced men. The depth of the alluvium, from 10 to 200 feet, makes prospecting exceedingly costly. Prospect shafts cost $6 to $8 a foot, and every pay streak that has been found represents an enormous outlay for

unsuccessful prospecting. Therefore the Fairbanks district proper is eminently not the place for prospectors of small means, but affords splendid opportunities for those with good financial backing. In adjacent areas, however, such as parts of the Tenderfoot district, where the alluvium is much shallower, there are much better chances for the individual miner. It must be remembered that these outlying districts are but little easier of access than they were a few years ago.

There was a great scarcity of water in the Fairbanks district up to the last week in August, after which time there was considerable rain. One of the most favorable features about the Fairbanks district is the fact that the work goes on throughout the year, thus giving steady employment to miners and assuring a more permanent population. In 1906 the summer production was probably not more than 50 per cent of the total.

Means of communication are being rapidly extended. Nearly all the large producing creeks are now connected by wagon roads, either with water transportation on the Tanana, or with the Tanana Mines Railway. This, together with the telegraph and telephone lines, much facilitates business.

Cleary, Fairbanks, Dome, Vault, Esther, Goldstream, and Pedro creeks and their tributaries are the chief producing creeks of the district. Cleary continues to stand first in production, with Fairbanks in second place. The finding of values on Cripple and Treasure creeks definitely extends the producing area to the southwest, and reported discoveries of gold in the upper Chena may show a northeasterly extension of the same belt, though this is not yet established.

The facts in hand are, however, sufficient to determine that there is a gold-bearing zone, at least 10 miles wide, running northeast and southwest, which has been traced for about 30 miles. Its northeastern extension would intersect the upper Chena basin, while to the southwest it runs out into Tolovana flats. A logical deduction from these facts would suggest that the prospector should turn his attention to the Chena basin and to the streams draining the upland which bounds the Tolovana flats on the east. It should be remembered, however, that the investigations so far made indicate that the conditions which bring about mineralization are local, and hence the formation of placers probably does not persist over any great distance.

Worthy of special note are the rich placers found last year on Vault Creek, which had previously been unproductive. On nearly all the producing streams which are tributary to the Chatanika the pay streak has been traced well down to the main river. In fact, the origin of the rich gravels found in various places at 100 to 200 feet depth under the valley floor of the Chatanika is among the most puz-

zling of the phenomena connected with the placers of this district. Interest in Goldstream Creek was revived during last summer by some rich placer discoveries, and as a result, though the creek was almost abandoned in the early part of the summer, later it was studded with operators for several miles.

Mine operators are rapidly recognizing the necessity of making available all of the water supply tributary to the gold-bearing area. At best the water supply during dry weather is very scant and on some creeks is practically nil. Among the largest ditch-building schemes is that involving the construction of a water main from the upper drainage basins of the Chatanika, for which surveys have been made. It is estimated that this ditch, which is to bring the water of Faith, McManus, Pool, and Smith creeks to the Fairbanks-Cleary divide, will be 72 miles long. It is currently reported that the low-water discharge of these streams is about 5,000 miner's inches at the proposed intake, but these figures the writer has no means of verifying.

Of the outlying districts tributary to Fairbanks the Tenderfoot probably made the largest production, estimated at $100,000. The gravels on Tenderfoot Creek are deep, but in the smaller creeks are said not to exceed 8 to 10 feet in depth. It would appear that these deposits lie in a different zone from those of Fairbanks.

Some work was done on the streams tributary to the upper Chatanika, where probably 30 men were at work. Some gold has been found on Faith, Hope, and Homestake creeks. The pay streak is thin and the values are said to be regularly distributed.

The region lying south of Fairbanks, including the Bonnifield and Kantishna districts, is described by Mr. Prindle (pp. 205–221), and the Birch Creek district by the writer (pp. 187–204), elsewhere in this report.

RAMPART DISTRICT.

The total gold output of the Rampart district for 1906 is estimated to have a value of $270,000. The writer is indebted for valuable information to Messrs. H. F. Thumm and E. H. Chapman, of Rampart. Mr. Thumm states that about 33 claims were worked during the winter of 1906 and 17 during the summer, giving employment to about 100 men in winter and about twice as many in summer. New creeks not producing last year are Boothby and Skookum.

Three hydraulic plants were operated during part of the summer, one each on Hoosier, Ruby, and Hunter creeks. The Alaska Road Commission has begun the construction of a highway from Rampart up Big Minook. This when completed will materially reduce the cost of all mining operations.

Another road has been built from Baker Hot Springs to Glenn Creek, a distance of 24 miles, by Thomas Manley, a large owner of mining

property. This road affords a natural outlet to Tanana River for the Glenn Creek region. Mr. Manley has also surveyed a ditch line from Hutlinana Creek to Thanksgiving Creek, a distance of 15 miles. If the scheme is carried out and there is sufficient water it will lead to extensive mining developments in the Glenn Creek region. It is of interest to note that the same operator has imported a churn drill for prospecting, the first in the district.

KOYUKUK DISTRICT.

Little information is at hand regarding the remote Koyukuk district, but it is reported that the gold production in 1906 was about $150,000 or $200,000. There has been no reduction in cost of operations, and until such takes place there will probably be no expansion of the mining. It is said that there are about 200 men in the Koyukuk district, and that the richest placers are on Newlands Creek. During the past winter a stampede took place on Johns River, but it appears that nothing of value was found.

Late in the summer of 1906 a report came to Fairbanks of the discovery of new placer ground in the Chandlar basin. The Chandlar is tributary to the Yukon from the northwest about 20 miles below Fort Yukon. Auriferous gravels have long been known to occur in this region,[a] but no workable placers have previously been found. A stream called Big Creek is reported to be the scene of the new find.

FORTYMILE REGION.[b]

The area usually included under the name Fortymile region embraces the basin of Fortymile River as well as the placer district tributary to the town of Eagle. Though the oldest of the Yukon camps, progress has been very slow, chiefly because of the lack of transportation facilities. This is being remedied to a certain extent by the construction of a wagon road to Steele Creek.

Upward of 200 men are working in this district, probably on half as many claims. The principal producing creeks are Jack Wade, Chicken, and Lost Chicken, together with their tributaries. The producing creeks in the region tributary to Eagle include several confluent to Seventymile Creek, together with American Creek and some smaller streams.

Considerable interest has been taken in the Fortymile region in the subject of dredges, but no plants have yet been set up. There are also plans for ditch building, but these have not gone beyond preliminary surveys.

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[a] Schrader, F. C., Preliminary report on a reconnaissance along Chandlar and Koyukuk rivers: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 341-423.

[b] The writer is indebted to Messrs. Elmer R. Brady, commissioner at Jack Wade, and U. G. Myers, commissioner at Eagle, for information about the Fortymile region.

The writer is indebted to C. B. McDowell, of the Fortymile region, Alaska, for the following statement in regard to the developments in that district:

As dredging has proved so successful in the Klondike, many efforts are being initiated here looking toward working this section in a similar manner. Russell King, of London, has purchased several miles of Walkers Fork and is now installing a 5-foot bucket dredge on the properties. He expects to begin operations in the early part of June. The McDowell-Allen Company is also installing a dipper dredge on South Fork of Fortymile River and likewise expects to begin operations early in the summer. A company installed a dredge on the Canadian side of Fortymile River late last summer and will work its ground in this fashion the coming summer. Another dredge is now being installed at the boundary on the Fortymile for operations this summer. G. L. Savage, of New York, began operations late last fall on a ditch line to carry water from Mosquito Fork into the Chicken Creek basin for hydraulic purposes. Considerable prospecting for quartz was carried on last year, and while there were two good surface showings found—one gold and one copper—sufficient work has not yet been done to demonstrate whether they are of any great value or not.

According to the statement of J. H. Van Zandt, deputy collector at Fortymile, 11,974 ounces of gold were shipped through his office in 1906. The entire production of this district in 1900 is estimated to have a value of $300,000.

THE ALASKA COAL FIELDS.

By G. C. Martin.

INTRODUCTION.

The coal resources of Alaska have been the subject of a large amount of investigation by the Geological Survey in recent years. Since 1902 special coal investigations have been in progress each year and have yielded a fairly accurate knowledge of the more important coal fields. In addition to this a large amount of information concerning coal has been gathered each year since regular geologic work was begun in Alaska, by Survey parties that were working primarily on other problems.

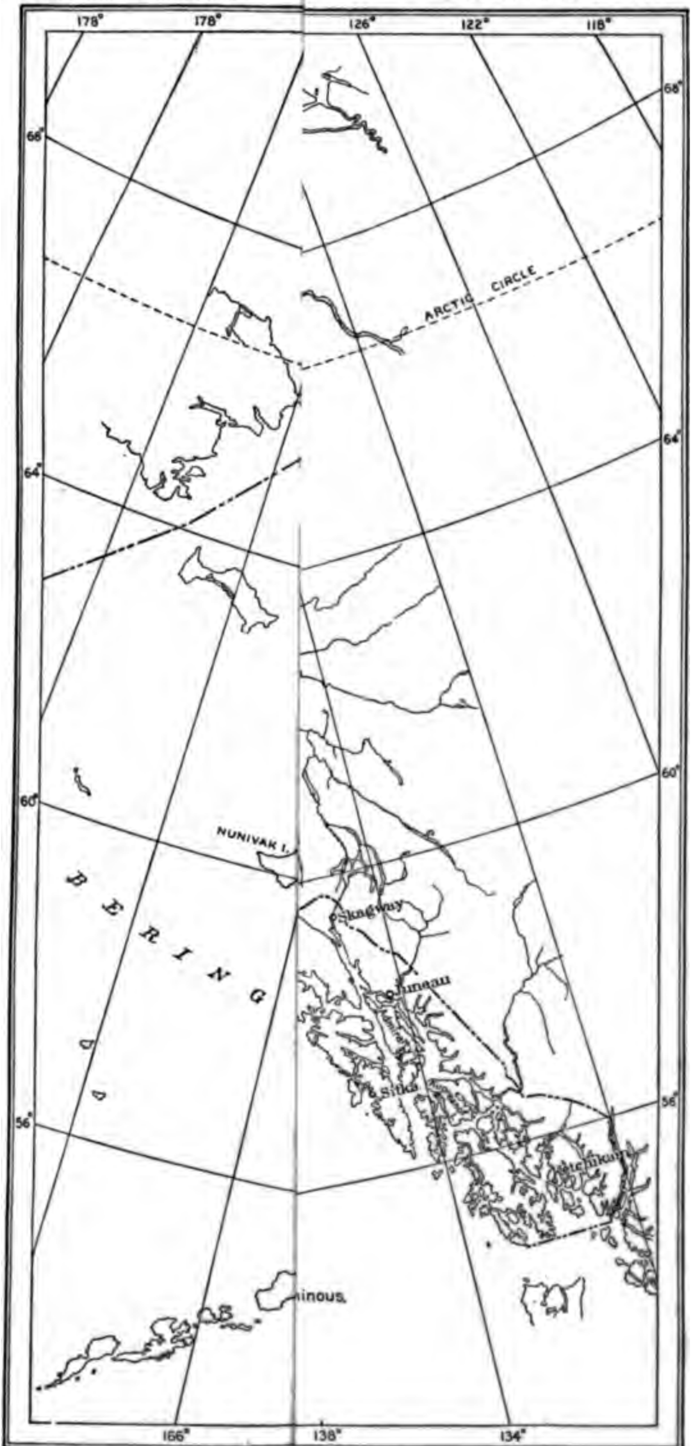
Existing knowledge of the coal of Alaska was summarized by Dall[a] in 1896 and again by Brooks[b] in 1902; but the large increase in detailed information in the last few years makes it desirable to bring together the following brief summary, which will lay greatest emphasis on the larger problems which have recently been or which are yet to be solved. It is not intended to be complete in itself, but is supplementary to the more comprehensive summaries already published and preliminary to more detailed discussions which will be possible on the completion of the investigations now in progress.

DISTRIBUTION AND AREA.

The distribution of the coal fields of Alaska is indicated on the accompanying map (Pl. II), which shows (1) known areas of high-grade coal (anthracite and semibituminous) of workable thickness; (2) known areas of lower grade coal (bituminous and sub-bituminous) of workable thickness; (3) known areas of workable lignites, and (4) areas of coal-bearing rocks. The last item includes those areas which are known to contain some coal but in which beds thick enough to be mined have not yet been discovered; areas in which coal has been authentically reported but concerning which detailed information is lacking, and areas in which the character of the rocks is similar to that in neighboring coal fields and where consequently the occurrence of coal is to be expected. These statements apply also to the subjoined table of areas. The areas mapped as "coal-bearing rocks"

[a] Dall, W. H., Report on the coal and lignite of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, pp. 769-908.

[b] Brooks, A. H., Coal resources of Alaska: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 515-571.



178°
178°
126°
122°
118°
68°
66°
64°
64°
60°
60°
56°
56°
ARCTIC CIRCLE
NUNIVAK I.
B E R I N G
Skagway
Juneau
Sitka
Ketchikan
inous
166°
138°
134°

KNOWN.

are consequently not well defined and must be regarded as subject to considerable changes by subsequent exploration. They are intended to indicate the regions in which new discoveries of coal seem, in the light of our present knowledge, to be most probable. The extent of the various areas noted above, as well as the area of each individual coal field, is shown in the following table, which gives a total of at least 1,238 square miles, or 792,320 acres, of known workable coal and 12,644 square miles, or 8,092,160 acres, of "coal-bearing rocks."

Areas of Alaska coal fields.[a]

	Known coal areas.	Areas of coal-bearing rocks.[b]
	Square miles.	*Square miles.*
Anthracite:		
Bering River	26.4	
Matanuska River	4.2	
	30.6	
Semibituminous:		
Bering River	20.2	620
Matanuska River	20.3	
Cape Lisburne	14.2	
	54.7	620
Bituminous:		
Matanuska River	22	900
Alaska Peninsula	69	657
Yukon basin	167	2,490
Cape Lisburne	205	1,255
Anaktuvuk River	9	68
	472	5,370
Total anthracite and bituminous	557.3	5,990
Lignite:		
Southeastern Alaska	10	50
Cook Inlet region	304	2,565
Southwestern Alaska	16	300
Copper River		20
Yukon basin	216	1,557
Bering Sea	52	426
Northern Alaska	83	1,736
	681	6,654
Grand total	1,238	12,644

a The differences between the areas given here and those published elsewhere are due chiefly to the recognition of four classes of coal instead of three, and the consequent division of the Lisburne areas into semibituminous and bituminous and of the Yukon areas into bituminous and lignite, and of similar changes in other smaller areas.

b See explanation on p. 40.

GEOLOGY OF THE COAL-BEARING ROCKS.

The geologic position of Alaska coals is distributed through horizons in the Carboniferous, the Jurassic, the Cretaceous, and the Tertiary. The abundance of the coal and the extent of the areas increase progressively from the older to the younger horizons, reaching their culmination not later than the Miocene.

It should be noted in this connection that the old belief that the age of coal is an index of its quality does not hold uniformly in Alaska or elsewhere. This belief contains a partial truth in Alaska as in other regions, but other factors are always locally of greater weight. The

Carboniferous coals of Alaska are of higher grade than those of the Jurassic or the Cretaceous, and the Jurassic coals are better than some of the Cretaceous coals. The Cretaceous in turn includes some coal which is of better quality than much of the Tertiary coal. Thus far it would seem as if the theory of the increase in quality of coal with its age were supported by the evidence from Alaska. But when the Tertiary coals are considered it is found that they include many beds and considerable areas which outrank in quality all the other coals of Alaska and which are equaled only at a few areas in other regions. The truth of the matter is that the conditions favorable for the formation of high-grade coal, including character of sedimentation and degree of alteration, are dependent on local conditions and are independent of the age of the coal.

Carboniferous coal is known to exist in commercial quantities at Cape Lisburne and smaller amounts are known at other localities. The Carboniferous coal beds at Cape Lisburne are in the lower Carboniferous, which there comprises a lower group consisting of slates, shales, and limestones and containing several coal beds; a middle group of black cherts, slates, shales, and cherty limestones; and an upper group of massive limestones of great thickness, which seem to shade off into massive white cherts. Coal beds of Permian age have been worked near Nation River on the upper Yukon, but they appear to be of slight extent and of little importance, although the quality is good. Rocks of probable Carboniferous or Permian age are known to contain coaly shales and thin coal seams at various localities in the valley of White River and indicate that workable coal beds may yet be discovered in them.

Jurassic rocks have a wide distribution in Alaska, and they are known to be coal bearing in several places. The largest known area of Jurassic coal is at Cape Lisburne, where a horizon of undetermined position in the Jurassic is represented. The Wainwright Inlet coal is probably of the same horizon. At least part of the coal at Herendeen Bay may be Jurassic, though other coal-bearing horizons are represented. The eastern extension of the Matanuska coal field includes large areas of middle and upper Jurassic rocks in which some coal is present.

Cretaceous rocks cover large and widely distributed areas in Alaska and are coal bearing at many localities. Cretaceous coal is present on Anaktuvuk River, a tributary of the Colville, which flows into the Arctic Ocean, in the lower Yukon Valley, possibly at the headwaters of the Matanuska, and at Chignik Bay and Herendeen Bay, in southwestern Alaska. All these deposits except that in the Matanuska Valley represent the upper Cretaceous.

Tertiary coal is widely distributed in Alaska, being known from many localities along the Pacific coast, from the interior, and from the Arctic slope. The position of the coal within the Tertiary is

rather indefinite, the evidence being incomplete and conflicting. The Tertiary coal-bearing rocks on the Yukon rest upon the Cretaceous with an apparent conformity, thus suggesting that the lower beds are basal Eocene or even transitional from the Mesozoic to the Cenozoic. Other evidence, including the relation of the floras of the Kenai formation to those of other regions and the relation of these beds to the overlying Miocene, indicates that the Kenai coal is upper Eocene or Oligocene. The coal floras on Bering River include forms suggesting those of the Kenai and other forms which are strangers to those beds and which Knowlton considers possibly Miocene. Still younger coal occurs at Yakutat Bay, where there are no rocks of Kenai age and where the floras belong very high in the Tertiary. The total evidence thus suggests that the Tertiary coal of Alaska occurs at several distinct horizons.

OCCURRENCE OF COAL.[a]

PACIFIC COAST REGION.

The Pacific coast coal fields are of moderate area but of wide distribution. They include both Mesozoic and Tertiary coals, with the complete range in composition from a good quality of anthracite, through high-grade, semibituminous steam and coking coals and ordi-

[a] The following references include the latest and most complete reports on each region. Earlier reports of importance, when referred to in later ones, are not mentioned here.

PACIFIC COAST REGION.

MARTIN, G. C., The distribution and character of Bering River coal: Bull. U. S. Geol. Survey No. 284, 1906, pp. 65–77.

——— A reconnaissance of the Matanuska coal field, Alaska, in 1905: Bull. U. S. Geol. Survey No. 289, 1906, 36 pp.

——— Geology and mineral resources of the Controller Bay region. (In preparation.)

PAIGE, SIDNEY, The Herendeen Bay coal field: Bull. U. S. Geol. Survey No. 284, 1906, pp. 101–106.

PAIGE, SIDNEY, and KNOPF, ADOLPH, A reconnaissance in the Matanuska and Talkeetna basins. (In this volume, pp. 104–115.)

STONE, R. W., Coal resources of southwestern Alaska: Bull. U. S. Geol. Survey No. 259, 1905, pp. 151–171.

——— Coal fields of the Kachemak Bay region: Bull. U. S. Geol. Survey No. 277, 1906, pp. 53–73.

WRIGHT, C. W., A reconnaissance of Admiralty Island, Alaska: Bull. U. S. Geol. Survey No. 287, 1907, pp. 151–154.

INTERIOR REGION.

COLLIER, A. J., Coal resources of the Yukon basin, Alaska: Bull. U. S. Geol. Survey No. 218, 1903, 71 pp.

MENDENHALL, W. C., Geology of the central Copper River region, Alaska: Prof. Paper U. S. Geol. Survey No. 41, 1905, pp. 123–125.

PRINDLE, L. M., The Bonnifield and Kantishna regions. (In this volume, pp. 221–226.)

BERING SEA AND ARCTIC SLOPE.

BROOKS, A. H., Coal resources of Alaska: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 515–571.

COLLIER, A. J., Geology and coal resources of the Cape Lisburne region: Bull. U. S. Geol. Survey No. 278, 1906, 54 pp.

MOFFIT, F. H., The Fairhaven gold placers, Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 247, 1905, p. 67.

SCHRADER, F. C., Reconnaissance in northern Alaska across the Rocky Mountains, along Koyukuk, John, Anaktuvuk, and Colville rivers and the Arctic coast to Cape Lisburne, in 1901: Prof. Paper U. S. Geol. Survey No. 20, 1904, pp. 106–114.

nary bituminous coal, to lignites of various character. Many of the coal beds are of great thickness, especially where the coal is of high carbonization, but unfortunately the high grade of coal and the great thickness of the beds are as a rule accompanied by an irregularity of the geologic structure that is unfavorable to mining conditions. The Pacific coast coals are in general favorably situated for shipment, and in this respect, as in the character of some of the coal, offer possibilities for a larger, more regular, and wider market than any of the other Alaska coals.

INTERIOR REGION.

The interior region, which is here defined to include the valleys of Copper and Yukon rivers and their tributaries, contains Cretaceous bituminous coal on the lower Yukon and Tertiary lignite and subbituminous coal on the upper Yukon and in the Tanana, Koyukuk, and Copper river basins. None of this coal is suitable for export, but it may be of considerable importance as local fuel.

BERING SEA AND ARCTIC SLOPE.

The coal of the Bering Sea and Arctic slope region includes great range in geologic age and great variety in character. Coal is present in the Carboniferous, Jurassic, Cretaceous, and Tertiary. The Cape Lisburne coal includes Carboniferous semibituminous and Jurassic bituminous, and in the Colville basin Cretaceous bituminous coal and Tertiary lignite are present. The other coal, as far as is now known (except the Wainwright Inlet coal, which is Jurassic), is all lignite of Tertiary age.

It is not likely that any of this coal is of immediate value for other than local use. The high-grade coal at Cape Lisburne may find an extensive market at Nome, but the shipping problems are serious. The other coal is of such character that its market must be restricted to local regions in which the cost of better imported coal is high. It may be of extreme importance and of great value in local operations, but it is not good enough to ship very far from the mines.

CHARACTER OF THE COAL.

The character of the coal in the Alaska fields has been stated in the previously published descriptions of the various fields and has been referred to in the preceding pages. A detailed discussion of this subject is consequently not necessary here. The following table is a summary of all the analyses of Alaska coal which have been made for the Geological Survey, and shows approximately the character and value of the coal from the known areas:

Analyses of Alaska coal.

	District and kind of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Fuel ratio.
	ANTHRACITE.						
1	Bering River, average of 7 analyses	7.88	6.15	78.23	7.74	1.30	12.86
2	Matanuska River, 1 sample	2.55	7.08	84.32	6.05	.57	11.90
	SEMIBITUMINOUS.						
3	Bering River, coking, average of 11 analyses	4.76	13.27	74.84	7.12	1.51	5.68
4	Cape Lisburne, average of 3 analyses	3.66	17.47	75.95	2.92	.96	4.46
5	Matanuska River, coking, average of 16 analyses	2.71	20.23	65.39	11.60	.57	3.23
	BITUMINOUS.						
6	Lower Yukon, average of 11 analyses	4.68	31.14	56.62	7.56	.48	1.90
	SUB-BITUMINOUS.						
7	Matanuska River, average of 4 analyses	6.56	35.43	49.44	8.57	.37	1.40
8	Koyukuk River, 1 sample	4.47	34.32	48.26	12.95	....	1.40
9	Nation River, 1 sample	1.39	40.02	55.55	3.04	2.98	1.39
10	Alaska Peninsula, average of 5 analyses	2.34	38.68	49.75	9.22	1.07	1.30
11	Cape Lisburne, average of 11 analyses	9.35	38.01	47.19	5.45	.35	1.24
12	Anaktuvuk River, 1 sample	6.85	36.39	43.38	13.38	.54	1.20
	LIGNITE.						
13	Port Graham, 1 sample	16.87	37.48	39.12	6.53	.39	1.04
14	Southeastern Alaska, average of 5 samples	1.97	37.84	35.18	24.23	.57	1.02
15	Wainwright Inlet, 1 sample	10.65	42.99	42.94	3.42	.62	1.00
16	Colville River, 1 sample	11.50	30.33	30.27	27.90	.50	1.00
17	Upper Yukon, Canadian, average of 13 analyses	13.08	39.88	39.28	7.72	1.26	.99
18	Upper Yukon, Circle province, average of 3 analyses	10.45	41.81	40.49	7.27	1.30	.97
19	Upper Yukon, Rampart province, average of 6 analyses	11.42	41.15	36.95	10.48	.33	.91
20	Seward Peninsula, 1 sample	24.92	38.15	33.58	3.35	.68	.88
21	Chitistone River, 1 sample	1.65	51.50	40.75	6.10	....	.79
22	Kachemak Bay, average of 6 analyses	19.85	40.48	30.99	8.68	.35	.77
23	Cantwell River, 1 sample	13.02	48.81	32.40	5.77	.16	.66
24	Kodiak Island, 1 sample	12.31	51.48	33.80	2.41	.17	.66
25	Unga Island, average of 2 analyses	10.92	53.36	28.25	7.47	1.36	.62
26	Tyonek, average of 4 analyses	8.35	54.20	30.92	6.53	.38	.58
27	Chistochina River, 1 sample	15.91	60.35	19.46	4.28	....	.32

1. Bull. U. S. Geol. Survey No. 284, p. 74, analyses 1 to 7.
2. Bull. U. S. Geol. Survey No. 284, p. 98, analysis 1.
3. Bull. U. S. Geol. Survey No. 284, p. 74, analyses 10 to 20.
4. Bull. U. S. Geol. Survey No. 278, p. 47, analyses 13 to 15.
5. Bull. U. S. Geol. Survey No. 284, p. 98, analyses 2 to 17.
6. Bull. U. S. Geol. Survey No. 218, pp. 62, 63, analyses 26, 28 to 38.
7. Bull. U. S. Geol. Survey No. 284, p. 98, analyses 18 to 21.
8. Bull. U. S. Geol. Survey No. 218, p. 62, analysis 28.
9. Bull. U. S. Geol. Survey No. 218, p. 62, analysis 17.
10. Bull. U. S. Geol. Survey No. 284, p. 27.
11. Bull. U. S. Geol. Survey No. 278, p. 47, analyses 1 to 7, 9 to 12.
12. Prof. Paper U. S. Geol. Survey No. 20, p. 114, analysis 607.
13. Bull. U. S. Geol. Survey No. 259, p. 170.
14. Bull. U. S. Geol. Survey No. 284, p. 27.
15. Prof. Paper U. S. Geol. Survey No. 20, p. 114, analysis 653.
16. Prof. Paper U. S. Geol. Survey No. 20, p. 114, analysis 620.
17. Bull. U. S. Geol. Survey No. 218, pp. 61, 62, analyses 3 to 15.
18. Bull. U. S. Geol. Survey No. 218, p. 62, analyses 16, 18, 19.
19. Bull. U. S. Geol. Survey No. 218, p. 62, analyses 20 to 25.
20. Bull. U. S. Geol. Survey No. 247, p. 67.
21. Prof. Paper U. S. Geol. Survey No. 41, p. 125.
22. Bull. U. S. Geol. Survey No. 259, p. 170, analyses 3, 4, 7 to 10.
23. Bull. U. S. Geol. Survey No. 218, p. 62.
24. Bull. U. S. Geol. Survey No. 259, p. 170.
25. Bull. U. S. Geol. Survey No. 259, p. 170.
26. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, p. 23, analyses 1 to 4.
27. Prof. Paper U. S. Geol. Survey No. 41, p. 124.

DEVELOPMENTS AND PRODUCTION.

The coal-mining industry of Alaska is still in a practically undeveloped condition. Coal has been mined intermittently and on a small scale at several places for many years, but the industry has never been

of much importance. This has been because the better coal has not been well known until recently and can not be shipped without railway connections from the mines to tide water, and also because no adequate provision has been made for granting title to sufficient tracts to assure profits on the large investments which are required.

The most active mining operations have been on Cook Inlet, in southwestern Alaska, on the Yukon, in Seward Peninsula, and at Cape Lisburne. All of these were for the purposes of local fuel on small coastwise or river steamers, at mining camps, and at canneries.

The amount and value of the coal produced in the last ten years are stated in the following table:

Production of coal in Alaska, 1897–1906.[a]

Year.	Quantity (short tons).	Value.	Year.	Quantity (short tons).	Value.
1897	2,000	$28,000	1902	2,212	$19,048
1898	1,000	14,000	1903	747	6,582
1899	1,200	16,800	1904	694	1,725
1900	1,200	16,800	1905	3,774	13,250
1901	1,300	15,600	1906	6,600	20,000

[a] The production for 1897, 1898, and 1906 is estimated. That for the other years is according to returns from the operators as published in Mineral Resources of the United States. These figures are known in some cases to be considerably below the true production, several operators not having reported at all.

The most important developments which are now going on are preparatory to mining the high-grade Matanuska and Bering River coal on a large scale for shipment away from the coal fields. These coals are adapted to use[a] on ocean steamers and railways and for the manufacture of coke, and for other purposes for which high-grade coal is required. Before they can be mined it will be necessary to build about 150 miles of railroad[b] to reach the Matanuska coal, and from 25 to 100 miles (according to the harbor chosen) to reach the Bering River coal. It is believed that either of these projects is legitimate, and that if favorable title can be obtained both fields will be producing on a large scale within a few years. Railroads are now under construction to both these fields.

The coal of the interior and northern parts of Alaska will probably be dependent on local demands[a] for its market as long as better coal remains nearer the seaboard. These local markets will depend chiefly on mining camps and will be transient or permanent according to whether the mining camps are placer or lode. Such coal fields of the interior as may be on the line of railroads or near lode mines, especially if the ores are smelting ores and the coal capable of coking, will attain considerable importance, but these conditions are contingent on future discoveries and developments which can not be foretold.

[a] Martin, G. C., Markets for Alaska coal: Bull. U. S. Geol. Survey No. 284, 1906, pp. 18-29.
[b] Brooks, A. H., Railway routes: Bull. U. S. Geol. Survey No. 284, 1906, pp. 10-17.

LODE MINING IN SOUTHEASTERN ALASKA.

By CHARLES W. WRIGHT.

INTRODUCTION.

The results of the developments in the lode mines of southeastern Alaska during the year have been encouraging. Many of the prospects have grown into metal producers, and the mines have with but few exceptions increased their output. The Ketchikan district, the most active in these advances, is now an established mining center. In the Juneau district considerable progress has been made, though much looked-for development did not materialize. Mining interest in the Sitka district was renewed by the discoveries and successful explorations near Cape Edward, on Chichagof Island, but no important mine improvements are to be noted in either the Wrangell or Skagway districts.

The investigations of each successive field season bring forth new facts bearing on the geologic as well as the economic conditions in the southeastern portion of Alaska. Although much of the information contained in the present report has already been published,[a] it is, nevertheless, advisable to repeat the general facts so as to combine with them the results of the present year. In this manner the important conclusions are presented without delay, and the more detailed discussions of the geology and mines are given in the separate reports[b] on each district.

GEOLOGY.

Only those few geologic facts can here be given which are necessary to an intelligent description of the mines and which may also serve in some degree to guide the prospector in his search for new ore bodies.

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[a] Wright, F. E. and C. W., Economic developments in southeastern Alaska: Bull. U. S. Geol. Survey No. 259, 1905, pp. 47–68; Lode mining in southeastern Alaska: Bull. U. S. Geol. Survey No. 284, 1906, pp. 30–54.

[b] Spencer, A. C., The Juneau gold belt; Wright, C. W., A reconnaissance of Admiralty Island: Bull. U. S. Geol. Survey No. 287, 1906. Brooks, A. H., Preliminary report on the Ketchikan mining district: Prof. Paper U. S. Geol. Survey No. 1, 1902. Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts (in preparation).

BEDDED ROCKS.

Limestone, slate, sandstone, and conglomerate, with intercalated greenstone and tuff beds, constitute the stratified rocks. In most places these have been profoundly metamorphosed and are represented by the crystalline limestones, mica and chlorite schists, cherts, and graywackes.

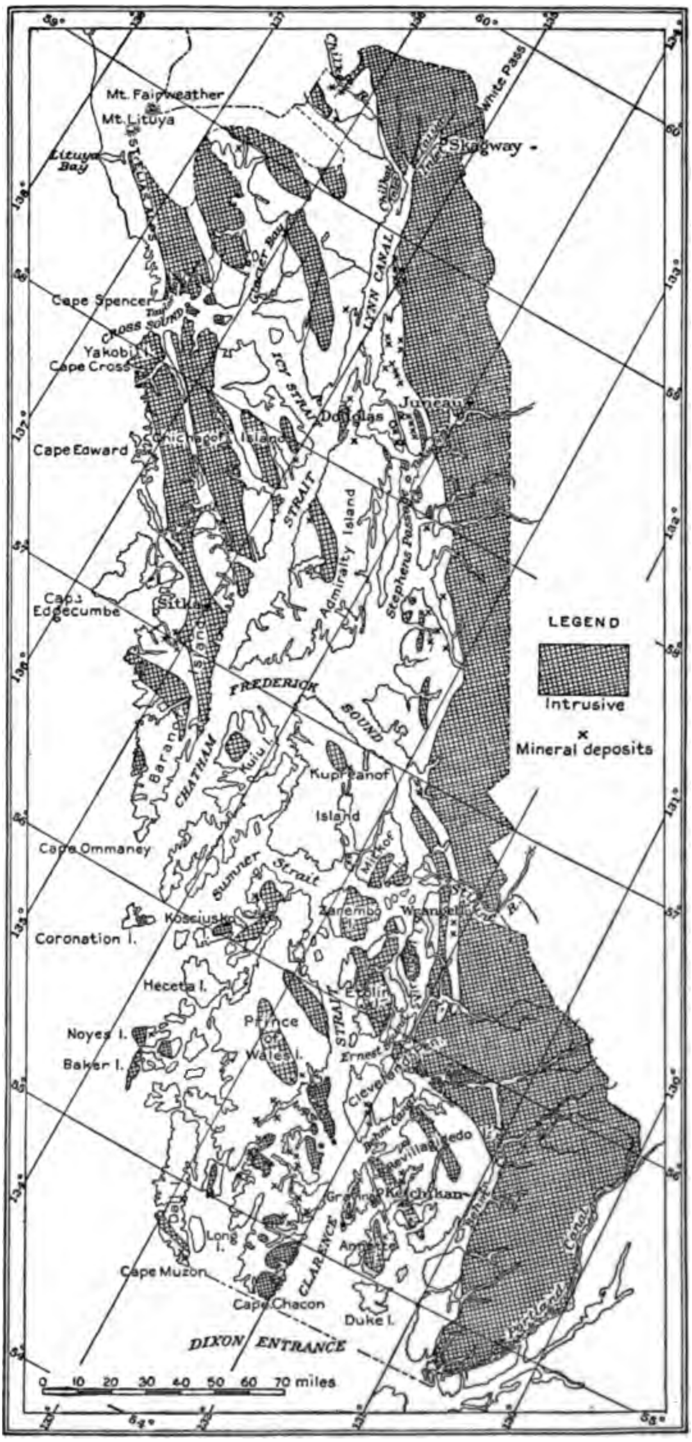
By far the greater portion of the rock strata are of Paleozoic age. These consist of the metamorphic limestones, schists, cherts, greenstones, and other rock types, which together form the underlying bedded rocks of the entire area. The Mesozoic and Tertiary formations are represented by the unmetamorphosed conglomerate, sandstone, and shale beds, which in places are coal bearing. They are only local in occurrence and of no great extent, occupying limited areas on Admiralty, Kupreanof, Kuiu, and Prince of Wales islands. Basaltic lava flows of late Tertiary age cover the southern portion of Admiralty Island, the northeast side of Kuiu Island, the south shore of Kupreanof Island, and a small area on the south end of Prince of Wales Island. Overlying these rock strata are beds of clay and gravel and the recent volcanics at Mount Edgecumbe and at points along the mainland.

INTRUSIVE ROCKS.

The intrusive rocks occupy about one-half of the aggregate land area of southeastern Alaska, as is well shown on the accompanying map (Pl. III). Coarse granular rocks, granitic in character, form the great mass of the Coast Range bordering the mainland and occupy wide areas in the central portion of many of the islands. They are in direct relation to the geologic structure, and their longitudinal axes and lines of contact parallel the direction of strike of the bedded rocks. Such intrusives vary in composition from granodiorite to quartz diorite and hornblende diorite. In general they invade the Paleozoic bedded rocks, but do not cut the more recent Mesozoic beds. Other intrusives are those of andesite, diabase, basalt, and melaphyr, usually in the form of dikes cutting both the older and younger sedimentary rocks.

STRUCTURE.

The sedimentary formations distributed along the mainland strip and adjacent islands all strike northwest and dip, as a rule, steeply to the northeast. The structure of the outer islands includes two separate systems of large and small folds. The main system, which is the younger of the two, has a northwesterly axial trend and is most pronounced adjacent to the wide areas of the intrusive rocks—namely, along the mainland and on Chichagof and Baranof islands. The minor system, which in most places has been obliterated by the



MAP OF SOUTHEASTERN ALASKA, SHOWING DISTRIBUTION OF MINERAL DEPOSITS AND AREAS OF INTRUSIVE ROCKS.

later and more intense folding of the beds, has a northeasterly axial trend and is prominent in the less disturbed and less metamorphosed areas. In many places both directions of folding are observed, those having the northeasterly trend being represented by a number of minor folds, which as a whole are combined in much broader anticlines or synclines having a northwesterly trend. Observations of this sort were made along the north shore of Chichagof Island and the west coast of Prince of Wales Island.

MINERALIZATION.

The direct relation of mineralization, or the occurrence of ore, to the rock structure and to the intrusive rocks is very evident. Without exception the ore bodies are found in the vicinity of, or more rarely in, the larger intrusive masses, and only in those places where the rock structure in general has a northwesterly trend. In a broad way the mineralization is confined within contact aureoles of the granitic and metamorphic rocks. Along the main Coast Range granite belt this contact zone is several miles in width, whereas along the outlying granite belts of the islands it is but a few miles wide. The larger areas occupied by this intrusive rock, so far as known, are shown on the sketch map (Pl. III), and the positions of the mines and prospects are indicated by crosses.

The most extensive and productive area is the Juneau gold belt, which has been irregularly traced along the contact of the Coast Range intrusive from Windham Bay to a point 10 miles north of Berners Bay, where it enters Lynn Canal, a total length of 120 miles and a width of less than 10 miles.[a]

The Admiralty Island mineral zone starts at a point just north of Mole Harbor on the west side of Seymour Canal and may be traced northwestward. It includes the Young Bay and Funter Bay deposits, crosses Lynn Canal, and is again exposed in St. James Bay and above the main forks of Endicott River. Mining and prospecting within this zone have been extensive but have met with little success.[b]

In the Sitka mining district a mineral zone begins on the southeast shore of Baranof Island and follows in a northwesterly direction along the west flank of a large granitic belt which forms the backbone of Chichagof and Baranof islands. Five miles above Cape Edward this belt enters the Pacific Ocean. Within this mineral zone the important deposits are quartz veins of free-milling gold ore. Several such veins in the Silver Bay region have been mined and have been productive in past years, and at the present time the Cape Edward prospects are making small shipments of gold ore.

[a] Spencer, A. C., The Juneau gold belt: Bull. U. S. Geol. Survey No. 287, 1906.

[b] Wright, C. W., A reconnaissance of Admiralty Island: Bull. U. S. Geol. Survey No. 287, 1906, pp. 138-155.

A second, less important zone of mineralization follows the east flank of the granitic belt already mentioned, though in this zone no ore bodies of consequence have been developed. The belt includes several prospects at the head of Hooniah Sound and Idaho Inlet. A northern continuation of this zone appears to traverse the head of the several bays northwest of Cape Spencer as far as Lituya Bay.

On Kupreanof Island are scattered indications of a widespread mineral-bearing zone, which extends from the head of Portage Bay down the east side of Duncan Canal and includes prospects along the west shore of Wrangell Narrows. The ore bodies thus far opened carry small values in both copper and gold. No deposits of ore have yet been discovered on Kuiu Island.

On Prince of Wales Island the regularity of the rock structure is locally interrupted by the broad and irregular intrusive masses, and for this reason the ore bodies are not traceable along definite lines. Where zones of mineralization occur they follow the lines of contact of the intrusive rock masses closely, as is well shown, for example, at Copper Mountain and on Kasaan Peninsula.

ORE BODIES.

Within the zones described above mineralization is widespread, metallic sulphides occur disseminated throughout most of the beds, and quartz veins or veinlets are everywhere present. A sample taken almost anywhere within such areas will usually yield a trace of gold and silver, though concentrations of these metals into workable deposits are much less numerous than one would anticipate with the vast amount of mineralization present.

The ore bodies are of many types. Strong gold-bearing quartz veins of moderate-grade ore, occurring either in the intrusive rocks or adjacent metamorphic rocks, are mined at Berners Bay, Eagle River, and Sheep Creek, in the Juneau district; on the west coast of Chichagof Island, north of Sitka; at Helm Bay and Dolomi near Ketchikan; and at many other localities. Lodes or stringer leads in the slates and schists or following wide dikes of a mineralized basic rock are most strongly developed up Gold Creek in the vicinity of Juneau and at numerous other points along the mainland belt.

Bands of heavily mineralized schist following the trend of the rock structure and cut by rich ore seams are shown at the Nevada Creek mines on Douglas Island, the Gold Stream mine on Gravina Island, and at other localities. The ore bodies of the Treadwell group of mines, as shown by Becker[a] and Spencer,[b] are brecciated masses of intrusive syenite, intersected by a network of quartz and calcite veinlets and impregnated with pyrite, which is found both in the veinlets

[a] Becker, G. F., Reconnaissance of the gold fields of southern Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 1-86.

[b] Spencer, A. C., The Juneau gold belt: Bull. U. S. Geol. Survey No. 287, 1906, pp. 93-115.

and in the rock itself. The ore bodies are several hundred feet in width and several thousand feet in length. No similar deposits have been discovered elsewhere in Alaska.

The copper deposits prominent on Prince of Wales Island can not be classed under the above-mentioned forms of occurrence. They are, with few exceptions, irregular lenses or masses of chalcopyrite ore, many of them rich in magnetite, and occur either as replacement or contact deposits adjacent to a granitic intrusive mass, and more rarely as heavily impregnated portions of schists.

GOLD.

OCCURRENCE.

Although gold is universally distributed along the coastal mountains of southeastern Alaska in lodes, and less commonly in placer deposits, there are relatively few localities which show a sufficient concentration of auriferous minerals to make valuable ore bodies, and in these places the ore is usually low in grade. The possibility of mining such ores, however, is obvious when one considers the available water power and favorable means of transportation the country affords. In the gold-quartz veins or lodes the gold is found both in the native state and also combined with metallic sulphides, which usually penetrate into the inclosing country rock. These quartz-filled fissures were formed subsequent to the general metamorphism of the coastal mountain range and after the granodioritic invasion, and their content is in genetic relation to the intrusive rock.

PRODUCTION.

The subjoined table shows the gold produced in southeastern Alaska in 1905. The placer deposits yield but a very small proportion of the gold production, their total output in 1906 being less than $20,000. Placer mining was advanced at only two localities, in Silverbow Basin and at Windfall Creek.

Production of the gold mines in southeastern Alaska, 1905.

Ore mined.	Gold.		Silver.		Average per ton.			
					Gold.		Silver.	
	Amount.	Value.	Amount.	Value.	Amount.	Value.	Amount.	Value.
Tons. 1,365,316	*Ounces.* 162,353	$3,335,466	*Ounces.* 31,110	$18,789	*Ounces.* 0.118	$2.44	*Ounces.* 0.023	$0.014

To the above figures must be added the gold produced from the copper mines, which amounted to $71,170 in gold and $16,021 in silver. It should also be stated that nine-tenths of the total output was from the Treadwell group of mines on Douglas Island.

The gold production for 1906 will slightly exceed that for 1905.

JUNEAU MINING DISTRICT.[a]

Those mines which were operated during the year in the Juneau district have, with hardly an exception, given satisfactory returns, though many of the new and extensive developments that were planned failed of accomplishment. Two large stamp mills, at the head of Gold Creek and on Nevada Creek, were built, and the capacity of some of the power plants and mills at present in operation was increased.

MINES OF DOUGLAS ISLAND.

Douglas Island, though small, has become widely known as the locality of the Treadwell group of mines. The geologic features of the Treadwell deposits and the methods of mining employed have been discussed in detail by Spencer [b] and by Kinzie.[c]

At the Alaska-Treadwell mine the shaft has now reached a depth of 1,500 feet, and from it the 1,450-foot level is being opened. Other developments have been confined to the 1,050-foot and 1,250-foot levels. There is apparently little change in the character and value of the ore with increasing depth. On the surface the Glory Hole, or open-pit workings, have reached the 330-foot level below the adit tunnel, and the ore is being mined close up to the walls. The open-pit method of mining will not be carried below this level. Most of the ore milled has come from the stopes on the 600-foot, 750-foot, 900-foot, and 1,050-foot levels. The annual report for the year ending May 31, 1906, states that a total of 888,411 tons of ore was milled during the year, yielding $1,902,455, or $1.07 per ton in bullion and $1.07 per ton in concentrates. The mining and development expense was $0.84 per ton, and the cost of milling $0.15 per ton. For the shipping and treatment of concentrates $0.12 per ton is to be added, and this with minor expenses makes the total operating cost $1.19 per ton of ore milled.

On the Seven Hundred Foot fraction operations were renewed this year and considerable ore was mined from the 660-foot level. On the 770- and 880-foot levels developments were advanced and some ore was mined. The lowest, or 990-foot, level was opened and the sample returns were reported to be encouraging.

The Mexican mine is now developing its 880-foot, 990-foot, and 1,100-foot levels. The ore mined has been mainly from the 550-foot

[a] As the detailed report by A. C. Spencer on the Juneau gold belt (Bull. U. S. Geol. Survey No. 287) has recently been published, only brief mention will be made of the late improvements on the mines within this area.

[b] Op. cit.

[c] Kinzie, R. A., The Treadwell group of mines, Alaska: Trans. Am. Inst. Min. Eng., vol. 34, 1904, pp. 334-386.

and 660-foot levels, and to some extent from the 770-foot and 880-foot levels. The last annual report gave a total of 233,985 tons ore milled to January 1, 1906, yielding $703,765, or an average of $3.01 per ton.

At the Ready Bullion mine the inclined shaft has been sunk to the 1,500-foot level and developments furthered on the 1,350-foot and 1,200-foot levels. The ore mined was principally from the 750-foot and 1,025-foot levels. The yearly report to January 1, 1906, gave a total tonnage of 233,480 tons, yielding $439,815.

The power plants that operate this group of mines have undergone many interesting changes within the last year. The supply of water power has been increased by the building of a new dam at the headwaters of Fish Creek, thus forming a storage basin which will increase the supply by 200 miner's inches during the two months of low water in the winter. This will increase the amount of all ore milled by water power from 87 per cent to 93 per cent. Another large saving is to be made by the use of oil in place of coal, thus doing away with a large expense in the handling of coal and a reduction in the initial cost. For this purpose large supply tanks are being installed, pipe lines laid, and oil burners introduced in the boilers.

The Nevada Creek mine, belonging to the Alaska Treasure Consolidated Mines Company, on the southeast end of Douglas Island, has been energetically developed this year, both underground and with reference to surface improvements. The mine is located 1 mile from tide water, at an elevation of 825 feet. At this point a tunnel 700 feet in length has been driven in a southwesterly direction, nearly at right angles to the trend of the rock structure. Drifts 100 to 300 feet in length have been extended to the northwest and southeast from points 450 and 550 feet from the mouth of the tunnel, and from these other exploratory crosscuts have been driven. The country rock is essentially greenstone and greenstone schist, with intercalated bands of graphitic slate. The ore bodies may be defined as narrow bands parallel with the rock structure within which a concentration of metallic minerals has taken place. The ore minerals, essentially auriferous pyrite with sulphides of copper, lead, and zinc, are accompanied by both quartz and calcite veinlets. Intruding these rock beds are narrow dikes of basalt, striking in a northwesterly direction, which appear to have little effect on the ore occurrence. A change in the structural trend or a wrinkling of the schistose beds is indicative of an ore body. At such a place, 450 feet from the mouth of the tunnel, an ore body 10 feet wide and containing a narrow seam of high-grade quartz ore 2 to 12 inches wide is being opened. The values in this body appear to be limited to a distance of 100 feet along its strike, and the rock structure indicates that the deposit is in the form of a shoot pitching at an angle of 40° in a northwesterly direction and parallel

with the axis of minor folding or wrinkling. The present underground developments are confined to the exploration of this ore body.

From tide water to the mine a cable tramway 1 mile in length has been built. Just below the main tunnel a 20-stamp mill has been erected and was to be in operation by the end of 1906. For power purposes a 450-foot flume, with intake at 1,050 feet elevation on Nevada Creek, is connected by a pipe line 925 feet long with the compressor plant and mill at 750 feet elevation.

The operations on the Red Diamond group at the head of Nevada Creek, which were started the year previous, were discontinued early in 1906. On the Mammoth group and other adjacent properties assessment work alone was done.

The properties of the Alaska Atlin Mining Company, the Yakamaw Mining Company, the Alaska Consolidated Mining Company, and others located on the island have been idle for several years, and no improvements of consequence have been made on them.

GOLD CREEK MINES.

The proposed mining improvements on the lode system which is strongly developed within the Gold Creek drainage and extends over the Sheep Creek divide were not accomplished, and progress in actual mining over the preceding year has been slight.

Briefly, the deposits are of low-grade, free-milling ore and occur within an 800-foot belt of black slate which has been intruded by numerous dikes 10 to 50 feet in width of a dark-brown, altered basic rock, probably a gabbro. Numerous quartz gash veins are present within this belt, cutting both bedded and intrusive rocks, but are most plentiful near their contact. The auriferous sulphides, essentially pyrrhotite and pyrite, impregnate both the black slate and dike rocks, but the values are principally in the quartz veins. The average value of the ore mined in a large way is very low, and this has to some extent discouraged the investments of capital necessary for their economic development. It has, however, been demonstrated at both the Ebner and Alaska-Juneau mines that the ore can be profitably mined. This, with the undoubted persistence of mineralization and values in the lode system to a depth below which mining will likely go, should tend to encourage mining operations.

Operations at the Ebner mine were continuous during the year, and results similar to those of former years were attained. In the upper tunnel the drifts were extended 350 feet, and in the lower tunnel 150 feet of drifting was done. During the year the 15-stamp mill on the property was in continuous operation except for a few weeks in the winter. The water power of Gold Creek at this point was sufficient to develop 125 horsepower throughout this period.

At the Alaska-Juneau mine operations were renewed in May and continued until November, as in previous years. During this time the 30-stamp mill was in continuous operation, an average of 4,200 tons of rock being milled per month. The ore mined was mainly from the open cuts and raises which were driven to open the back pits at lower levels.

At the Perseverance mine the greater portion of the work done was in the erection of a 100-stamp mill, which is to begin operations early in 1907. In the mine developments have been confined to an ore body 60 to 80 feet wide, consisting of a heavily mineralized black slate, cut by numerous quartz veins carrying pyrrhotite, chalcopyrite, galena, and sphalerite. This lode has a general northwesterly strike and dips 65° NE. At the time of the writer's visit it was exposed by a drift 1,000 feet in length at tunnel level and partially by a raise 920 feet long from the tunnel to the surface. From this raise 100 feet above the tunnel an intermediate drift, 350 feet long, has been driven in both directions along the lode and connected by raises with the tunnel drift. Other levels at intervals of 100 feet will be started from this main raise.

On the Boston group of claims, at the mouth of Gold Creek, a mineralized dike 50 feet wide is exposed similar to those found at the Ebner mine. This dike as a whole forms a very low-grade ore, and as yet no attempt has been made to begin its extraction in large quantities. The annual assessment work has been accomplished from year to year, and the present developments consist of a shaft 118 feet deep, from which 500 feet of drifting and crosscutting have been extended.

No improvements worthy of note were made on any of the other lode mines or prospects within the Gold Creek or Sheep Creek drainage areas last year.

The placer deposits of Silverbow Basin were again leased by the Silver Bow Hydraulic Company, and operations began the latter part of April and closed the latter part of October. During September work was suspended because of low water. The gravels were worked by a hydraulic giant having a 6-inch nozzle, and bowlders were handled by a cable with boat attachment. The gravel bank under attack is 75 feet high and in it the highest values are found where the oxidized sand streaks are present.

At the lower basin, on the property of the Jualpa Mining Company, no attempt was made to mine the gravels.

MINES NORTH OF JUNEAU.

SALMON CREEK.

At the mouth of Salmon Creek, the first stream north of Juneau, is the Wagner group of claims, located on a mineralized basic dike from 8 to 12 feet wide, cut by numerous quartz veinlets. This corresponds in character to the exposures on the Boston group mentioned above and lies in the same line of strike. Three other similar dikes were observed outcropping at different elevations on the mountain slope above. A total of 675 feet of tunneling has been driven 250 feet along the vein and 425 feet crosscutting the country rock. A small 2-stamp mill has been installed for test purposes.

MONTANA CREEK.

On McGinnis Creek, the eastern branch of Montana Creek, are the properties of the Mansfield Gold Mining Company, consisting of both lode and placer claims. These properties are located on the northeastern portion of the wide mineral belt, but all attempts to work either placer or lode deposits have failed, mainly because of their lowness of gold values. During most of the year this property was idle.

There has been no change in the mining conditions or developments on the Montana Basin group of claims at the head of the creek. Small amounts of assessment work were done and some additional surveys made. The inaccessibility and distance from salt water appear to be the chief cause for their nondevelopment.

WINDFALL CREEK.

Just above the divide from Montana Creek, at the head of Windfall Creek, is the Smith & Heid group of claims, located upon low-grade belts of mineralized schist and greenstone, traversed by quartz veinlets in which the gold values are irregularly distributed. There was no renewal of interest in this property during the year.

The first of May the Detroit-Alaska Mining Company began operations on its placer claims on the lower portion of the creek, half a mile above Windfall Lake. Work was continued at intervals until September 15, but owing to lack of water the actual number of days of gravel washing was only 28. A total of 1,000 cubic yards was sluiced. The gravels are of moderate grade and, with a sufficient water supply, should yield profitable returns.

PETERSON CREEK.

On the Peterson group of claims work has been continuous on the gold-quartz veins by the owner and a few helpers. A small testing mill has been erected, and it is reported that from this mill sufficient gold bullion is recovered to defray mining expenses.

EAGLE RIVER.

At the Eagle River mine there has been a steady output during the year, and the 20-stamp mill has been in operation most of the time. The ore body, which is a wide quartz vein containing shoots of rich ore, is displaced by faulting, which is apparently confined to a depth of a few hundred feet from the surface. These displacements have shattered the country rock across considerable width and have been the cause of much trouble in the exploitation of the vein and in the extraction of the ore from it. Late reports, however, state that developments have extended into the solid formation below the faulted area, and that the vein is apparently in place. The total amount of drifting, crosscutting, and shaft sinking amounts to about 6,000 feet.

YANKEE BASIN.

The principal work done in the Yankee Basin area was the driving of a crosscut tunnel to undercut the Dividend and Cascade lodes. This tunnel begins at a point just above the miner's cabin and was 400 feet in length in October of last year. It was estimated to undercut the Dividend lode at a distance of 530 feet and the Cascade at 1,200 feet from the mouth of the tunnel.

Except the small annual developments necessary no important progress was made on any of the other mines or prospects in this belt, extending as far as Berners Bay.

BERNERS BAY.

The limits of the Berners Bay region include the drainage areas of both Johnson and Sherman creeks. Extensive mineral bodies, consisting of huge stockwork deposits, well-defined fissure veins, and lodes, are exposed up these creeks. From these ore bodies the total gold production has been nearly a million dollars in value, the larger portion of which was obtained from the Sherman Creek mine previous to 1900.

Since 1901 the only producing property has been the Jualin mine, located on Johnson Creek, 4 miles from its mouth and 730 feet above tide water. Three separate ore bodies, inclosed in the diorite country rock and having a general northwesterly trend and a dip of 60° NE., are exposed in the mine workings. Of these the foot-wall vein carries the highest values, and upon it mining and developments have been concentrated this last year. This west vein, as it is called, is a strong quartz-filled fissure, about 400 feet in length and averaging 5 feet in width. Just below the adit level a fault was encountered with steep pitch toward the northwest; the displacement, however, was not great and the vein was readily recovered. This year a 50-foot inclined shaft was sunk from the 170-foot level below the adit tunnel.

At this depth, 220 feet below the adit tunnel, drifts were extended to the northwest and southeast along the vein and the ore thus developed was mined.

In 1906 operations were begun the first of May and discontinued in October, and during this period the 10-stamp mill on the property was operated without interruption.

At the other mines within the Berners Bay region no additional developments have been made, principally because of litigation difficulties. The nature of the ore deposits and mine developments at these points was discussed in last year's report.[a]

MINES SOUTH OF JUNEAU.

Mining progress during the last year has been very slight along the mainland belt to the south of Juneau. None of the mines or prospects have been extensively worked, and their production has been nil.

At Taku Harbor and Limestone Inlet gold-bearing veins of exceptional promise are said to have been opened up during the year, but little work was done on them. At Port Snettisham the only work reported was on the Crystal mine. Here the quartz ore was being mined in a small way and milled in the 5-stamp mill on the property, yielding profitable returns. No noteworthy improvements were made on any of the other prospects about this inlet.

To the south the Holkham Bay group of claims, located on the south side of Endicott Arm, is reported to have been sold, and a small crew of men are to be employed during the winter to drive a 400-foot tunnel, which will develop the vein in depth. The ore body is a mineralized quartz lode, in a schist country rock, within 2 miles of the main Coast Range intrusive belt. The ore minerals are galena, arsenical pyrite, pyrite, and small particles of chalcopyrite, all of which occur both in the quartz veinlets and inclosed in fragments of country rock. Sixty per cent of the gold content is said to be free milling, and the concentrates contained in the ore are estimated at 2 per cent. At 1,800 feet elevation a tunnel undercuts the lode 175 feet from its mouth, and from this point nearly 200 feet of drifting has been extended. Other improvements consist mainly of surface cuts exposing the lode at various points along its strike.

At the Sumdum mine, in Holkham Bay, no attempt was made to renew operations, which were discontinued in 1904.

At most of the properties at the head of Windham Bay, which were energetically developed during 1902–3, operations were discontinued soon after that time. The only company which carried on active work in 1906 was the Helvetia Gold Mining Company. Long crosscut tunnels have been driven into the mineralized belts of schist, and

[a] Wright, F. E. and C. W., Lode mining in southeastern Alaska: Bull. U. S. Geol. Survey No. 284, 1906, pp. 31–34.

quartz stringers were followed by drifts. Tests have been made on the ore obtained in the 10-stamp mill on the Red Wing group, just below this company's property, but apparently the results were not encouraging.

Prospecting on the divide between Windham Bay and Endicott Arm has revealed several quartz veins, carrying moderate values, but their inaccessibility and distance from tide water render them of little economic value at present.

ADMIRALTY ISLAND.

The mining interests on Admiralty Island have changed but little, and on the two properties, the Portage group at Funter Bay and the Mammoth group at Young Bay, there has been a notable lack of development.

The deposit on the Portage group is a mineralized band of chlorite-mica schist, cut by quartz-calcite veinlets and containing small masses and particles of copper and iron sulphides scattered across a width of about 40 feet. This band has been exposed by an open cut, and the ore is apparently of low grade. Just below the open cut a tunnel was started to undercut the lode, 40 feet in depth. When visited, this tunnel was 30 feet in length and had not reached the ore.

Two miles southeast of the Portage group investigations have been in progress by the Mansfield Gold Mining Company on copper deposits, consisting of several quartz ledges, 3 to 6 feet wide, 100 feet or more apart, and striking northwest, parallel with the trend of the country rock. These deposits carry considerable chalcopyrite and pyrrhotite, also some galena and sphalerite. The main vein outcrops at 1,380 feet elevation on the north slope of Funter Mountain, and at this point has been exposed by a 20-foot tunnel and surface stripping. At 550 feet above tide water a crosscut tunnel has been started to investigate these veins in depth, and work in this tunnel will be furthered during the winter months.

On the Mammoth group, to the southeast of the Portage group and on the same mineral zone, the annual assessment work alone was done.

SITKA MINING DISTRICT.

GEOLOGY.

The geology of the Sitka district, which includes Baranof and Chichagof islands, is comparatively simple. The bedded rocks of the islands are in the main broadly folded Devonian limestone and chert beds with interstratified basaltic flows, and overlying these along the outer coast are slate-greenstone strata, which in turn are overlain by a wide belt made up of pre-Cretaceous graywackes and conglomerates. The most recent rock formations are represented by the lava beds

about Mount Edgecumbe. The core of both of the islands is made up of granitic intrusives, forming broad belts that strike across the island in a northwesterly direction and invading all the bedded rocks except the recent lavas. Near the contact of these granite masses are located the mineral deposits.

BARANOF ISLAND.

Many gold- and silver-bearing quartz veins and lodes, usually of low grade, have been discovered in the area adjacent to Silver Bay. Of importance are the Cache, Lucky Chance, Liberty, and Silver Bay prospects, at which much development work was done in former years. For a number of years, however, no attempt has been made to work these properties and only meager developments have been accomplished.

At Rodman Bay, on the north side of the island, mining operations were closed in 1904, and most of the machinery and mine equipment has been sold and removed from the property. A vast amount of capital was invested in these prospects, and not until a railroad and 120-stamp mill had been built did the investors realize the actual value of their mine.

Other prospects were observed in Port Conclusion and Port Lucy, but these, too, have been abandoned.

CHICHAGOF ISLAND.

The only area on Chichagof Island within which auriferous veins of importance have been discovered lies to the east of Cape Edward, an island point projecting into the Pacific Ocean. These deposits were first noted early in 1905 by Indian fishermen, and within the last two years valuable veins have been developed at this locality. The prospects are on the north and south slopes of a mountainous divide between Klag Bay and Hirst Cove. The country rock is made up of an outlying belt of slates, graywackes, and conglomerates constituting the lowlands along the coast and overlying the slate and greenstone tuff beds which compose the flanks of the bordering mountain range. Farther inland and to the east of this series belts of limestone interstratified with metamorphic schists skirt the contact of the granodiorite intrusive which forms the core of the island.

The auriferous veins so far discovered lie near the line of contact between the outlying slate-graywacke beds and the slate-greenstone strata, at a distance of 3 miles from the granodiorite belt to the northeast. These strata strike northwest and dip steeply to the southwest. The veins have a general trend parallel with the rock beds, though some of them crosscut decidedly and in a northerly direction. The occurrence of the ore in shoots is apparent from the localization of very rich ore at certain points and the barrenness of the veins at

other points. The gold is present both native and combined with the sulphides, the latter composing but a small percentage of the ore.

The Young group of claims, generally known as the De Groff mine, extends from tide water on the north side of Klag Bay for over half a mile up a gulch. The principal workings are at 220 feet elevation, where a crosscut 30 feet long undercuts the vein 45 feet in depth, and from the end of this crosscut over 100 feet of drifting has been extended. The vein has also been explored by surface trenches and is found to vary from 2 to 7 feet in width. The ore mined has been principally from the surface outcrops and masses of quartz float near the vein. This has been sorted, sacked, and shipped in several-ton lots to the smelter at Tacoma. The ore, however, is a free-milling quartz rock, and it is planned to erect a 5-stamp mill on the property early in the spring of 1907, and thus save the present shipping and smelting expense.

Just above the Young group to the northwest are the Golden Horn and Golden Gate claims, located upon quartz veins similar to the one already described. The ore body on the Golden Horn claim has been prospected by a tunnel about 40 feet in length, and a vein 3 to 6 feet wide is exposed. On the Golden Gate claim the developments consist of surface cuts exposing a strong fissure vein many hundred feet in length. Though the values are found to be low, shoots of rich ore are likely to occur.

Over the divide and down the north slope of the mountain is the Bear group of claims. The workings are in a gulch half a mile from Hirst Cove and at 440 feet elevation. The quartz vein at this point is but a foot in width, though the country rock itself for a few feet on each side of the vein is sufficiently mineralized to make ore. In strike the vein coincides with the structure of the slate-greenstone schist inclosing rock, which trends N. 50° W. A small shipment of the ore was made to the Tacoma smelter and the returns were reported as favorable.

Along this mineral belt, bordering the outer shore of Chichagof Island, prospecting should be encouraged. The inaccessibility of the valleys and the dense undergrowth present a somewhat formidable outlook to the prospector; a careful search, however, within this area is undoubtedly warranted.

KETCHIKAN MINING DISTRICT.

Gold plays but a very minor rôle in the mining interests of the Ketchikan district, and its production has been largely from the copper ores, which carry from $0.50 to $2 in gold per ton of ore. In this section there are apparently no defined lines or zones along which gold has been extensively distributed. It is found scattered here and there at numerous localities, but at only a few of these have developments been extensive.

PRINCE OF WALES ISLAND.

Near Hollis, on the north side of Twelvemile Arm, are the Crackerjack, Puyallup, Flora and Nellie, Dew Drop, and Julia claims. The most work done in this section was on the Julia claim, situated on Harris Creek, 2½ miles southwest of Hollis and from 800 to 1,200 feet from tide water. At this point a shaft 100 feet deep has been sunk on an incline of 25°. At the 50-foot level a drift has been run 35 feet long, and another started at the 100-foot level. The ore body is a quartz vein, striking north-northwest and dipping 25° SW., in a black-slate country rock. At the surface it has a width of 1 foot of solid quartz. This, however, becomes a stringer lead, consisting of numerous quartz veinlets across a width of 4½ feet, at a depth of 100 feet. The ore contains auriferous pyrite, with some galena and sphalerite. An arrastre was installed and mining on a small scale is to be advanced during the winter.

Investigations at the Crackerjack mine were made by the Brown-Alaska Company early in 1906, but no development work has since been done. The Puyallup mine was leased and prospected by two miners, who discontinued work in February, 1906. The other properties in this section were idle.

At the Treasure group, on Granite Mountain, which promised well to become a producer, only small improvements were made within the year, and on the near-by claims the assessment work alone was done.

At Dolomi a small crew of six men was employed and developments were furthered on the Valparaiso vein. The shaft has been extended to 180 feet in depth, and at the lower level the pay streak is reported to have widened from 16 inches to nearly 30 inches. On the Amazon claim limited explorations were also made underground. On the Paul and Lakeside claims inclined shafts 60 feet deep have been sunk and drifts started on the veins. The properties of the Golden Fleece Mining Company were sold by the action of the court early in the year and no attempt was made to operate them.

The prospects at Dakoo Harbor, on Dall Island, southwest of Prince of Wales Island, have been developed in a small way during the year, though no important improvements in the ore bodies are to be noted. The deposits at this point are quartz veins and lodes of low-grade ore.

GRAVINA ISLAND.

At the Gold Stream mine, on the east side of Gravina Island, operations were renewed July 15 and a dozen or more men were employed until the 1st of October. An exploratory drift was extended in a northwesterly direction from the shaft, and a body of good ore was

exposed. On the surface considerable investigations and improvements were also made. Two smelter shipments of ore were made during the year, but this ore is by no means a smelting ore. It contains a high percentage of free gold and but a small proportion of concentrates, and with careful amalgamation and separation it may be reduced at small cost.

REVILLAGIGEDO ISLAND.

The Sea Level mine, on Thorne Arm, which was one of the first gold mines of the district and has been idle since 1903, was carefully examined late in 1906, with the view of resuming operations early in 1907. The properties in the near vicinity of Ketchikan have all been closed.

CLEVELAND PENINSULA.

Mining and prospecting on Cleveland Peninsula have been confined to Helm Bay and Smuggler Cove, on the southwest end. Mineralization occurs in a narrow belt of schist and slate, and from this belt seams and pockets of rich free-gold ore have been mined. Though numerous claims are located upon this belt, the only important work done during the year was on the Gold Standard and Old Glory groups. At the former a 2-drill compressor plant was installed, besides exploratory work underground. The 5-stamp mill on the property was reported in October to have been in operation for sixty days, crushing 15 tons of ore per day. The richest ore is sorted out and shipped to the smelter. At the Old Glory group small developments were advanced and the ore obtained was treated in the 2-stamp testing mill on the property.

WRANGELL MINING DISTRICT.

Last year brought little progress in the mining enterprises of the Wrangell district. Late in the summer interest was revived on Woewodski Island by the Olympic Mining Company, and a renewed attempt was to be made to mine and mill the ore from the several quartz lodes and veins on this company's properties.

The mineral deposits are zones of brecciation in the greenstone country rock, from 5 to 15 feet in width, into which quartz has been generously introduced, carrying with it sulphide ores and small amounts of gold. But a small percentage of the ore is free milling, and as a whole the deposits are rather low in grade.

Though there are many other prospects in the district there was no gold production and but little mining was done within the year.

SKAGWAY MINING DISTRICT.

GENERAL STATEMENT.

There are no gold-quartz mines in the Skagway district. The only gold produced has been from the placer mines on Porcupine and Nugget creeks in the Chilkat drainage basin and from the beach diggings at Lituya Bay. These placer mines were mostly idle in 1906, and the production for the year was nil.

At Porcupine Creek nothing has been attempted since the washout in July, 1905. At Nugget Creek small improvements were made on some bench claims just above Salmon River, but no work was done on the deposits of this river.

LITUYA BAY.

Lituya Bay forms a deep indentation in the coast line 50 miles to the northwest of Cross Sound. Although it is an excellent harbor, a bar composed of large bowlders and gravel wash almost locks the entrance, and through the boat channel, which is but a hundred feet in width, the tide rushes at great velocity, so that it is dangerous to enter except at slack water during calm weather.

The lowlands flanking the abrupt mountain slopes at the head of the bay are composed of Pliocene conglomerate and shale beds carrying narrow seams of coal, the latter of no commercial importance. These strata overlie a belt of slates and greenstones, which in turn overlie the metamorphic schists exposed along the precipitous shore at the head of the bay. The mountain range in the background is composed essentially of an intrusive granodiorite. Indications of mineralization were observed in these schists bordering the granite belt, and from them the placer gold occurring in the beach sands along the coast is supposed to have originated.

The auriferous beach sands are distributed along the Pacific shore to the northwest of the bay for a distance of about 10 miles, and similar occurrences are reported at Yakutat. These auriferous deposits consist of black and ruby sands, occurring in layers from a few inches to a few feet thick and extending in places for 100 yards back from tide water. The black or magnetite sands are by far the richest, and a pan test gave numerous fine colors ranging from a fraction of a cent to several cents in value.

At a point 4 miles northwest of Lituya Bay a river which flows nearly parallel with the shore for about 3 miles enters the ocean, and here the fine wash which is derived from the mountain streams and carried in suspension is deposited by the counter action of the surf against the stream current. During periods of high tide and storms these auriferous sands are concentrated by the waves in layers high up on the beach. Since 1890 these deposits have been worked at

intervals, and are reported to have produced in 1891 $15,000.[a] In later years even higher returns are said to have been obtained, but no authentic statements could be procured.

In 1901 the Lituya Bay Gold Mining Company built a large warehouse and flumes and installed machinery to conduct large-scale operations, but the limited extent of the pay streaks and lack of near-by water for power and hydraulicking purposes prevented it from furthering the work to a successful outcome. Small parties of miners, however, at different periods have worked these deposits with shovel, sluice box, and rockers to good advantage, and report that the auriferous beds yielded from $5 to $10 a day per man. The presence of gold in these sands appears to warrant a thorough prospecting of the mineral-bearing schists which traverse the head of Lituya Bay and parallel the coast line.

COPPER.

PRODUCTION.

The remarkable increase in the production of copper from the mines on Prince of Wales Island has brought Alaska well to the front as a copper-producing territory. Practically the first shipments were made in the latter part of 1905, and since that time there has been a steadily increasing production. For the most part the ores of southeastern Alaska carry but a small percentage of copper and less than a dollar in gold, and therefore require exceptional mining and transportation conditions to insure profitable extraction.

The following table shows the amount and value of the copper, gold, and silver produced from copper ores in Alaska in 1905:

Production of copper ore in Alaska, 1905.

	Total.	Copper.		Gold.		Silver.	
		Amount.	Value.	Amount.	Value.	Amount.	Value.
	Tons.	*Pounds.*		*Ounces.*		*Ounces.*	
Total	52,199	4,805,238.0	$748,616.00	3,441.84	$71,170.36	26,500.00	$16,021.00
Average......per ton	....	92.6	14.44	.066	1.36	.497	.298

The production for the Prince William Sound area, as well as southeastern Alaska, is included in the above table, thus increasing the total by a little less than 3,000,000 pounds of copper. The ores from the Prince William Sound area are of comparatively high grade, and the averages per ton given in the table are higher than the yield from the ores in southeastern Alaska.

For 1906 the production of copper from southeastern Alaska alone is valued at nearly $1,000,000.

[a] Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 85.

KETCHIKAN MINING DISTRICT.

All the copper-producing mines of southeastern Alaska are on Prince of Wales Island, in the Ketchikan district. The ore bodies are genetically related to the intrusive rocks and occur either as contact or replacement deposits in the form of lenses or irregular masses. They are found in limestone, quartzite, or a greenstone-schist country rock. The chief copper ore is largely chalcopyrite, accompanied by pyrite, magnetite, and pyrrhotite, besides various gangue minerals. Enrichment zones are lacking, evidently on account of the absence of the zone of weathering which was removed during the glacial epoch; and at only one locality (Copper Mountain) are secondary ores present in quantity. At this place they extend only a few hundred feet below the surface.

KASAAN PENINSULA.

Kasaan Peninsula is a promontory 12 miles long and 3 to 6 miles wide, projecting into Clarence Strait and sheltering Kasaan Bay, a deep embayment. Its high points reach elevations of 500 to 3,000 feet, and the mountain mass is made up principally of eruptive rocks. The sedimentaries exposed are small areas of marbleized limestone and schists varying in composition. These are invaded by wide diorite masses and by dikes of felsite, diabase, andesite, and basalt, in many places forming an intricate complex of intrusives, both previous and subsequent to the deposition of the ore bodies. Faulting was observed locally, but displacements were small and their effect on the ore bodies was slight.

The ore bodies occur as lens-shaped masses within the contact aureole of the invading diorite batholiths. The diorite is not invariably exposed on the surface at the mine, but its presence may be usually found in the near vicinity. The presence of a huge underlying mass of igneous rock is clearly shown by the vast amount of contact metamorphism and contact minerals within the ore bodies. Garnet, epidote, hornblende, calcite masses, and many other secondary minerals are present and form the gangue of the copper deposits. Associated with the chalcopyrite is a large percentage of magnetite, thus making a base ore and necessitating the addition of much siliceous ore on its reduction in the smelter. This latter problem has been a source of difficulty the last few years, but has apparently been overcome by the development of extensive bodies of copper-bearing quartz at Maple Bay, on Portland Canal.

There is every reason to suppose that these copper deposits originated from considerable depth and were laid down from the solutions given off during the solidification of the dioritic batholiths. It seems safe to assume, therefore, that other ore bodies similar to those exposed on the surface may be found within the contact zones in depth.

The progress in mining development of the Mamie and Stevenstown mines, on the east side of the peninsula, may be best expressed in the number of tons of ore reduced in the smelter at Hadley, just below the two mines. This smelter, which began operations December 5, 1905, and was in blast at different periods for about two hundred and sixty days during the year 1906, reduced nearly 90,000 tons of ore, most of which was from the two mines mentioned.

At the Mamie mine notable progress was made and its output of ore was increased. Exploratory developments by drifts and diamond drill were also advanced.

The Stevenstown mine has had a successful year, with a large ore production. The ore body is much like that at the Mamie mine, consisting of a flat-lying lens of chalcopyrite-pyrite and some magnetite associated with hornblende and calcite. These lie in a banded garnet-epidote country rock and are crosscut by porphyrytic and diabasic dikes striking in various directions, most of which were intruded subsequent to the deposition of the ore. To the northeast a narrow belt of crystalline limestone was observed at one point overlying the ore body and apparently is the remnant of a broad limestone belt that has been removed by erosion. The developments consist of wide surface pits undercut by tunnels from which the ore is delivered to the aerial tram and thence to the smelter 1 mile distant.

An exploratory tunnel 300 feet in length, which undercuts a low-grade magnetite ore body exposed on the surface, has been driven on the Blue Jay claim, and at other points on the property small cuts and trenches have been made. It is planned to extend the investigation of these deposits by a diamond drill.

On the west slope of Kasaan Peninsula is the Mount Andrew mine, which for several years previous to 1906 was idle. The first of the year operations were renewed and were energetically advanced, so that at the time of the writer's visit, in October, the first ore shipments were being made to the smelter at Crofton, B. C. The underground workings consist of nearly 500 feet of tunnel drifts and crosscuts, and in the main tunnel two workable ore bodies, from 25 to 75 feet in lateral dimensions, have been opened. On the surface a third ore body, similar in size, but of somewhat lower grade, has been partially developed. A cable tram 3,600 feet long has been installed and large ore bins and a wharf have been built at tide water.

From the White Eagle mine a shipment of 350 tons of ore was made in February, but since that time work has been suspended. Prospecting during the summer between the White Eagle and Mount Andrew properties revealed new bodies of copper-bearing ores, which were located and exploitation was begun.

To the northwest, about 3 miles from the village of Kasaan, is the Mammoth group, purchased by the Haida Copper Company in June.

Previous developments at this mine consisted of a shaft 35 feet deep on the ore body, with two crosscuts 30 to 40 feet in length, and a 110-foot tunnel was started to undercut just below the shaft. Under the new management the tunnel was completed and a surface equipment comprising an aerial tram and wharf was being built preparatory to the shipping of ore early in 1907. The mine is at 480 feet elevation and 1,800 feet from tide water. The mineral deposit is a low-grade magnetite-chalcopyrite body with basic gangue minerals and is less than 100 feet in its greatest dimensions.

Four miles northwest of Kasaan post-office, and half a mile from the beach, locations were made in September upon an ore body of the Kasaan type. Soon after its discovery this property was bonded to a mining company that was planning to carry on its investigation during the winter.

Developments on the ore bodies at the Copper Queen mine, the Poor Man's group, and the Sunny Day group of claims, all situated on the Kasaan Bay side of the peninsula, have been suspended, principally on account of litigation, and the required assessment work alone has been done on them during the year.

The mines at Karta Bay, on the northwest end of the peninsula, have added considerable to the copper production of the island. The ore bodies are large magnetic masses, in which chalcopyrite occurs in concentrated patches and irregularly disseminated throughout the whole. These are included in an altered dioritic rock which intrudes and includes narrow beds of limestone and chlorite schist. The surrounding country is comparatively low in elevation, and shaft mining and exploration is a necessity. These magnetic bodies have been located by magnetic surveys, and the largest bodies of ore are apparently at the points of maximum attraction.

The Rush & Brown property, which is connected by a railroad 3½ miles in length with the wharf at Karta Bay, has been the mining center of the Karta Bay area. A lease of this mine was taken by the Alaska Copper Company, and the ore mined, which has amounted to several thousand tons, is shipped to its smelter at Coppermount. The deposit is a body of magnetite-chalcopyrite ore carrying small gold values and inclosed in a diorite country rock. It is oval in cross section, being 150 feet in length and 50 feet in width, and has been developed 100 feet in depth. A second ore body from 10 to 20 feet in width and of greater longitudinal extent occurs about 150 feet to the northeast, and from it much ore has been mined.

On the Venus group, 2 miles south of the Rush & Brown mine, a large body of pyrrhotite-chalcopyrite ore has been exposed by surface strippings and two short tunnels. The ore is low in grade, and little work was done on the property during the year.

SKOWL ARM.

During 1906 the Kiam mine, on Skowl Arm, and the adjoining Mammoth and Lake View groups to the east were idle. The smelter returns from a large shipment of the ore were not satisfactory, and its high content of sulphur made it an undesirable smelting product. After a careful examination made of these properties this last summer the owners decided to discontinue operations at this point.

The ore bodies which have been developed are heavily mineralized masses of pyrite and pyrrhotite ore containing chalcopyrite and occurring in a schist country rock. These masses coincide in trend and dip with the rock structure. At the Kiam mine the mineralized band is continuous over a length of possibly a thousand feet and has an average width of 20 feet, though in places it is 60 feet wide. In depth, however, the deposit was not undercut by the tunnels cross-cutting the ore-bearing zone, and it appears to be limited to some tens of feet from the surface at the point where it has been developed by the Powell tunnel. The tonnage of available ore is therefore relatively small, and though it could be readily mined its value is reported as insufficient for profitable extraction.

The Mammoth and Lake View groups are clearly in the general line of strike with the Kiam ore bodies, and so far as developed the deposits are of the same character. They appear to be merely smaller and weaker examples of the Kiam type.

NORTH ARM.

At the head of North Arm locations were made in 1905 on copper-bearing veins about a mile from tide water and less than a hundred feet in elevation. Early in 1906 these were transferred to the Cymru Mining Company, which immediately began operations and the 1st of October began shipments.

The veins, four of which have been exposed, lie in the limestone and greenstone-schist country rock and strike N. 35° W., nearly parallel to its structure, dipping 70° SE. They vary in width from 1 to 5 feet and contain chalcopyrite and pyrite scattered through a quartz gangue. Near the surface the ore is changed to the oxides and carbonates of iron and copper. A shaft 105 feet deep has been sunk on the larger of these veins and at the 100-foot level a drift extended. A large percentage of the ore mined was from a surface trench 500 feet long and 4 to 8 feet wide, following the vein. From these workings a surface tram leads to ore bunkers, from which the product is loaded directly into hulks or barges for shipment.

NIBLACK ANCHORAGE.

The Niblack mine, on the south side of Niblack Anchorage, has been operated steadily throughout the year and has yielded a large production of copper ore.

The ore bodies occur as mineralized portions of schist bands in a complex consisting chiefly of greenstone schists with a few belts of quartz-sericite schist and allied rock types. The formation strikes N. 60° W., with a dip of 60°–70° SW., and is cut by several later diabase dikes. Folding and faulting occur at many places and have an important bearing on the extent and shape of the ore bodies. Detailed work on these structural features in the mine has shown that the irregular outline of many of the ore bodies is the result of intersecting fault planes. The ore is essentially low-grade chalcopyrite, with small values in gold and silver. Pyrite occurs in great abundance and renders the ore suitable only for smelter treatment. Small veinlets of nearly pure chalcopyrite are associated with ferruginous quartz and constitute then the jasper ore of the miners.

The development work for the year was as follows: Drifting and crosscutting, 1,670 feet; shaft sinking, 80 feet; raises and winzes, 425 feet. The inclined shaft is now 225 feet deep and will be extended to a depth of 300 feet. On the 225-foot level a new ore body 90 feet long and 15 feet wide and following a diabase dike has been exposed. It extends to the 150-foot level above, and the ore from it was being mined.

HETTA INLET.

The mines on the west coast of Prince of Wales Island are centered within a small area about Copper Mountain and along the east shore of Hetta Inlet. A geologic sketch map of this area has already been published, with a description of the mines.[a] Briefly, the ore bodies are masses of chalcopyrite or carbonate ores associated with magnetite and pyrrhotite in a gangue of garnet, epidote, and calcite. As a rule these occur along the contact of a granitic stock, intruding beds of limestone and quartzite. The exceptions are the massive sulphide veins occurring in the greenstone schist at the Corbin and Copper City mines.

Investigations on the New York and Indiana claims, the principal holdings of the Alaska Copper Company, have been advanced throughout the year. The developments consist of several exploratory tunnels at different elevations below the surface exposures of the ore bodies, but no noteworthy ore exposures have been made in them.

On the north slope of Copper Mountain are the Jumbo mine workings, belonging to the Alaska Industrial Company, which are also upon contact deposits of chalcopyrite ore. The principal workings

[a] Bull. U. S. Geol. Survey No. 284, 1906, pp. 50–53.

are on Jumbo No. 4 claim, where three tunnels crosscut the contact zone and expose ore bodies at 1,650, 1,770, and 1,876 feet above sea level, and are themselves connected by raises. Similar ore masses have been opened by surface cuts at 2,000 feet elevation. From this mine a short aerial and surface tram connects with an aerial tram 8,228 feet long, over which the ore will be transported to 3,000-ton bins built on a wharf at tide water.

Other ore bodies developed in former years by this company are Jumbo Nos. 1 and 2 claims, and on the Green Monster group to the east, but these were neglected last year and mining was confined to the above-described property.

A mile to the north of the Jumbo claims are the Houghton claims, located along the granodiorite contact on similar chalcopyrite-magnetite deposits. These were transferred within the year to the Cuprite Copper Company, which has undertaken large developments.

Early in the year the Corbin property, 3 miles north of Copper Harbor, on the east shore of Hetta Inlet, was transferred to the Alaska Metals Company, which has begun developments, consisting essentially in the erection of buildings, a compressor plant, and wharf. The ore body is a narrow vein of massive sulphide ore, carrying but a slight percentage of copper and small values in gold and silver. It follows the general northwesterly structure of the greenstone-schist country rock. At a point 45 feet from the mouth of the tunnel to the south the vein narrows to a mere seam, and in the shaft, 22 feet below the surface, it was faulted. From all indications the deposit appears to be a small ore shoot, less than a hundred feet long and 3 feet wide, pitching at an angle of about 60° NW.

At the Copper City mine, 8 miles south of Copper Harbor, operations began in May and continued throughout the year. The ore body is a narrow vein of massive sulphide ore, occurring in the slate-greenstone schist country rock. The vein parallels the vein structure and varies from 1 foot to 5 feet in width. It is crosscut by dikes of diabase, which apparently are later than the deposition of the ore. Several shipments of the ore were made to the smelter at Tacoma during the year. The principal feature in the mine workings was the development of the vein below the 100-foot level. Along this level the ore body wedged away rather suddenly and was found to be displaced for a short distance toward the foot-wall side. At a point in the drift 60 feet northwest of the shaft a winze was being sunk on the vein to the 200-foot level, and in this a good width of ore was reported.

GRAVINA ISLAND.

Copper-bearing deposits are known to occur on both the south and north ends of Gravina Island. The properties at Seal Bay and on Dall Head were prospected to some extent during the summer, and

on the north end of the island west of Vallenar Bay new ore bodies were located. Developments were advanced by the Victor Copper Mining Company on the Bay View and War Eagle claims at Seal Bay. From the former a small smelter shipment was made, the ore being mined from a quartz vein carrying chalcopyrite, exposed along the south shore of the bay.

WRANGELL DISTRICT.

The mineral bodies exposed at the head of Duncan Canal and on Woewodski Island at the entrance both carry small percentages of copper. At the former locality little advance has been made on the groups of claims owned by the Portage Mountain Mining Company. On Woewodski Island the Olympic Mining Company renewed operations late in the summer at the Smith camp, and further investigations will be made on the quartz veins, which were extensively developed in former years.

SILVER, LEAD, AND ZINC.

Deposits of silver, lead, and zinc are not plentiful along the coastal belt, and except small amounts of silver accompanying the gold and copper ores the production has been nil.

The galena veins recently discovered in Cholmondeley Sound, on Prince of Wales Island, however, promise well to become producers in 1907. The Moonshine group of claims, situated at from 2,000 to 2,400 feet elevation on the east slope of Granite Mountain, in Cholmondeley Sound, was located in the spring and soon after was leased to a mining company, which began operations. The ore body, a well-defined vein or mineralized shear zone, obliquely traverses the limestone-schist country rock in a northeasterly direction and occupies a nearly vertical position. It has been exposed at points along the surface over a length of 600 feet and varies from 2 to 4 feet in width. The ore is massive galena associated with pyrite, chalcopyrite, and zinc blende in a gangue of quartz and calcite. Portions of the vein include brecciated masses of country rock, and at these points the distribution of the ore is irregular. The vein was being developed by two tunnels at 2,000 and 2,200 feet elevation and a shaft at 2,400 feet elevation. An aerial tram 5,000 feet long and a wharf must be built before shipments of the ore can be made.

In the Wrangell district explorations on the silver-lead properties located in Glacier and Groundhog basins on the mainland have been meager, and though these properties have been investigated by outside persons no mining company has yet undertaken their development, owing to their distance from tide water.

NONMETALLIFEROUS MINERAL RESOURCES OF SOUTH-EASTERN ALASKA.

By Charles W. Wright.

INTRODUCTION.

The recent developments and increasing production from the gypsum and marble quarries of southeastern Alaska have shown that the nonmetallic deposits are an important resource of this region. Structural minerals, such as marble, granite, gypsum, and cement, are widely distributed along this coast, and, besides these, both mineral and thermal springs have been found and coal seams located, though the latter are of no consequence at present.

Little consideration has been given to the nonmetallic products of this Territory, and the increasing use in the United States for such materials demands a more thorough investigation of these resources. Though distant from the market, many large deposits of structural material are well located for quarrying purposes and transportation by water.

In the following pages a brief description of the known workable deposits is given, together with a short discussion of their distribution and of the characteristics and market value of such nonmetalliferous materials.

ORNAMENTAL AND BUILDING STONES.

GENERAL STATEMENT.

The only stones of value in southeastern Alaska, so far known, are the marbles and granites. The market for these stones is in the cities along the Pacific coast, 600 to 1,000 miles distant. They must, therefore, be of more than ordinary quality to bear the expense of freight, as good stone is found in the vicinity of most large cities, and builders, as a rule, prefer to use a known rock which is near at hand and can be readily obtained.

To place the Alaskan product on the market, it will be necessary to establish supply stations with dressing and cutting plants in the larger seaboard cities, where cheaper and more efficient labor may be obtained than in Alaska. To supply these points, the rough granite

and marble blocks could be transported in hulks or barges carrying several thousand tons at a low freight rate and the necessity of careful handling during shipment would be avoided.

To determine the structural value of a building stone, microscopical, chemical, and physical tests should be made. This is more necessary for marbles and cement stone than for granite. Most university laboratories are equipped for such tests and will make them at a reasonable cost.

MARBLE.

DISTRIBUTION.

Beds of marble are known to occur at points along the mainland portion of southeastern Alaska, as well as on many of the islands. They are invariably at or near the contact of an intrusive belt of granodiorite, which has been one of the principal factors in metamorphosing the original limestone beds to their present crystalline or marbleized condition. The age of the limestone beds is Paleozoic, and only in a few places could a more definite determination be made. The largest deposit of marble under development is on the northwest end of Prince of Wales Island, near Shakan. This and other deposits are described on pages 75–77.

NECESSARY QUALITIES.

Commercially marble includes all limestone rocks susceptible of receiving a good polish and suitable for ornamental work. It is no simple problem to judge the value of a marble deposit, and this can not be done from mere tests of small samples, which, nevertheless, may often give significant results. Some of the more important factors governing the value of a body of marble are the quality and soundness of the material as a whole, extent of the deposit, absence of fractures or joint planes, color, lack of objectionable impurities—such as silica, pyrite, and bitumen—facility of extraction, and location of the deposit relative to the market and transportation.

COMPETITIVE DISTRICTS.

Most of the marble used in western cities for monumental and interior decorative purposes is furnished by eastern dealers and must be shipped across the continent. This is mainly the product of the Vermont and Tennessee quarries or is imported from Italy. Stevens County is the only producing locality in the State of Washington; there are none in Oregon, and but two of importance, the Inyo and Columbia quarries, in California. The total value of the marble production for 1905 from these localities was less than

$150,000. This product sold in a rough state at $1 to $2 per cubic foot, and dressed for ornamental and monumental purposes at $2 to $8 per cubic foot. Cut in slabs 1 inch to 2 inches thick and polished on one side the retail price varied from $0.50 to $1.50 per square foot. The eastern and foreign marbles sold for higher prices.

DESCRIPTION OF LOCALITIES.

PRINCE OF WALES ISLAND.

Several deposits of marble have been located on Prince of Wales Island, and, as stated above, the largest of these is at Marble Creek, a few miles north of Shakan, on the north side of the island. Other deposits are at El Capitan, also near Shakan; on Marble Island, adjacent to the northwest coast of Prince of Wales Island, and at Baldwin and Dolomi, on the east coast of the island.

At the Marble Creek locality are the properties of the Alaska Marble Company, located upon a belt of Devonian limestone half a mile or more in width flanking the contact of an intrusive granite mass which forms the low mountain ridge to the east and which is evidently the direct cause of its alteration to marble. Small dikes of diabase, much altered and faulted, though rare, were observed intersecting the marble beds, and apparently antedate the metamorphism of the limestone and the intrusion of the granite. They are, however, not sufficiently numerous to affect the value or expense of quarrying the marble, and in the present opening only one dike is exposed.

The extent of the deposit has been investigated by a number of drill holes and surface openings, and it is exposed at points over a length of 2 miles and a width of half a mile. Three varieties—pure white, blue veined with white background, and light blue, much of which has a mottled appearance—are found, the pure white rock being the most valuable. All of the marble is free from silica or flint beds, and though thin seams of pyrite were observed they do not occur in a quantity detrimental to the stone. Analysis of the rock shows 99.2 per cent calcium carbonate and 0.3 per cent magnesia. Though not equal to the best Italian grades, this marble is better than most American marbles and in the market will compete on at least equal terms with the Vermont, Georgia, and Tennessee products.

The principal workings on this deposit are 100 feet above sea level on the south side of Marble Creek and 3,200 feet from deep water. A gravity railroad extends from the quarry to the end of the wharf, where loading facilities have been erected. Quarrying has extended below the more or less jointed surface rock, and solid blocks 6 by 6 by 4 feet are being mined and shipped. With increasing depth

both soundness and quality of the marble greatly improve, and flawless blocks of large size may be quarried. The dimensions of these blocks, however, are dependent on the handling capacity of the machinery. Small shipments of this product have been made to many of the large cities as far east as Ohio, though the greater portion is sent to Tacoma, where a cutting and polishing plant has been built. Last year the capacity of the mining plant was materially increased with a view to an enlarged production in 1907.

On the opposite side of the low mountain range a similar marble deposit is exposed, and has been partially developed by the El Capitan Marble Company. This property is located on the north side of Klawak Passage, 6 miles from Shakan village. The marble exposed in the quarry close to tide water is comparable with that at Marble Creek above described, except in solidity. Thin fragments of the marble crumble more readily in the hand, and the position of the present workings is less favorable for extensive quarrying. A thousand feet back from tide water surface cuts and strippings have exposed a much firmer and better marble at the foot of a steep bluff. This company began operations in 1904, installed channeling and gadding machines, erected a marble-sawing plant, and made a small shipment. During the last two years no further quarrying has been done and only small developments have been made.

A number of marble claims were located in 1902 about 30 miles to the south of Shakan, on the northwest side of Marble Island, in Davidson Inlet, but practically no work was done on them and they were relocated in 1906. Several varieties of marble of good quality are exposed and the deposits appear worthy of further investigation.

At Baldwin, near the head of North Arm, an inlet on the east side of Prince of Wales Island, beds of marble have been located and developed by the American Coral Company. The deposit at this point consists of marble beds interstratified with chloritic schists striking N. 65° W., with a nearly vertical dip. The marble varies greatly in color and composition, and although some of it is of excellent quality it would probably be difficult to obtain any large quantity of a uniform grade. Most of the product contains a small percentage of silica and some alumina and magnesia. Pyrite in disseminated particles was also observed in some of the marble. The surface exposures were badly fractured in places, but this condition is probably confined to a depth of 10 to 20 feet from the surface. In 1905 a wharf was built, machinery installed, and buildings erected. In 1906, however, practically no work was done.

At the north entrance to Johnson Inlet, about 3 miles east of Dolomi, a second group of claims has been located by this company on a similar marble belt. Work at this point has been meager and but little was accomplished during 1906.

HAM ISLAND.

Two deposits of marble have been developed to some extent on Ham Island, an islet in Blake Channel at the southeast end of Wrangell Island. The Woodbridge-Lowery property lies on the west side and the Miller property on the east side. Exploratory work has been advanced at both localities, large blocks have been quarried, and from them many tombstones have been chiseled and polished for local use.

ADMIRALTY ISLAND.

A number of marble deposits occur on Admiralty Island—at Marble Bluffs on the west shore, at Square Cove, at Hood Bay, and in Chiak Bay. Some of the marble at these points is of excellent quality, but most of it contains silica and pyrite and is of an inferior grade. The deposits at Marble Bluffs are apparently the most extensive and of better grade than the others.

OTHER LOCALITIES.

Belts of marble exposed in cliffs at tide water have been located on the north side of George Inlet, also in Carroll Inlet to the southeast, both located on Revillagigedo Island. The extent and value of these marble beds have not been investigated.

On the mainland to the north, at the head of Limestone Inlet, 30 miles southeast of Juneau, extensive areas of a coarsely crystalline marble are located. The marble is colored and not of the best grade.

GRANITE.

DISTRIBUTION.

The granitic intrusive rocks occupy about one-half of the aggregate land area of southeastern Alaska. (See Pl. III, p. 48.) In composition they vary from granite to granodiorite and to quartz or hornblende diorite. The core of the Coast Range, as well as the central portion of many of the islands, is composed of this intrusive rock. The metamorphism in the granite, its nonuniformity in color, and the presence of joint cracks, so far as observed, make most of the stone undesirable for building purposes. However, granite masses of good quality, uniform in color, and favorably located for purposes of quarrying, were observed along the mainland up Portland Canal, in Behm Canal, at Thomas Bay, and Taku Inlet. On Baranof Island exposures of this rock of similar good quality occur at Gut Bay, on the east side, and at the head of Whale Bay and near Silver Bay, on the west side.

CHARACTERISTICS.

All the granite masses in southeastern Alaska are similar in composition, having plagioclase feldspar as an essential constituent. Hornblende is the usual dark mineral, though biotite mica is present in

much of the rock and in a few places exceeds in amount the hornblende. Quartz is commonly present, though usually in small amounts. The accessory components are apatite, titanite, and magnetite; secondary minerals, due to general metamorphism, are sericite, epidote, zoisite, chlorite, and calcite. Petrographically much of the rock is related more closely to the diorites than to the granites and is usually referred to as a diorite.

The prevailing color of the granite is a light gray and only in a few places were pink or reddish masses observed. The grains of the component minerals are ordinarily of medium size, not varying greatly in the different localities. Evidence of the durability of the granite is afforded in many places where long exposure to the influence of weathering has caused little or no disintegration of the surface.

MARKET.

No attempt has yet been made to quarry or even investigate the Alaskan granite. There is practically no market in Alaska for the stone, and along the Pacific coast to the south the demand has been supplied by the quarries in the States of Washington, Oregon, and California.

The long haul necessary to the market appears at first unfavorable to granite quarrying along this portion of the northwest coast, but the present freight rate of less than $2 per ton to Puget Sound is not greater than the cost of the transportation from some of the quarries in California to the larger cities. The cost for quarrying the stone in the State of Washington is estimated at 35 cents per cubic foot, and the proportion of marketable rock obtained from the amount quarried is about 60 per cent.

The value of the production of granite from States along the west coast amounted to nearly a million dollars in 1905. The average selling price per cubic foot for building and monumental purposes at the quarries in these States is given in the following table:

Average selling price per cubic foot of granite at the quarries in Pacific coast States.

	Rough.	Dressed.	For curbing.
California	$1.10	$5.20	$0.78
Washington	.60	2.20	.90
Oregon	.65	4.00	1.40

The above prices do not include the cost of transportation, which is from $0.50 to $3 per ton from the quarries to the cities. This adds from 5 to 30 cents to the cost per cubic foot.

GYPSUM.

OCCURRENCE.

Within the last two years extensive developments have been made on beds of gypsum at Iyoukeen Cove, on the east side of Chichagof Island, with encouraging results. The extent of this deposit, which occurs in the bottom of a valley, is practically unknown. There are only two exposures of this rock on Gypsum Creek, namely, at the lower and upper mine workings 1 mile from its mouth, and the entire area except a few outcrops of a cherty limestone is deeply buried by a dense undergrowth. The gypsum beds apparently overlie the Carboniferous rocks exposed along the southwestern shore of the cove and forming the southwestern valley divide, though the area of contact was buried under deep gravel deposits along the beach and in the valley. They are temporarily assigned to late Carboniferous or Permian formations. To the north the mountain is made up of a granite mass intruding the older limestone beds.

The geology in the immediate vicinity of the gypsum beds is obscure and neither foot nor hanging wall has been exposed in the mine workings. Bluffs of a cherty limestone striking northwest and dipping to the northeast are exposed near the entrance to the tunnel at the lower workings. The gypsum beds in the tunnel and lower levels have an east-west to N. 70° E. strike, with a northerly dip of 20° to 60°. Channels representing old watercourses and now filled with gravel wash are numerous throughout this deposit. These gravels resemble unconsolidated conglomerate beds and have been mistaken for both hanging and foot wall of the gypsum beds at points in the workings. A careful inspection of the gravels shows that the wash has the same character as that now in the creek bed. Of significance is the presence of granite cobbles corresponding to the intrusive mass at the head of the creek, which invaded the area subsequent to the deposition of the gypsum beds. Dikes of a basaltic rock were present in the beds, and one of these occurring at the south end of a drift on the first level was mistaken for the foot wall of the deposit.

DEVELOPMENTS.

This deposit, the property of the Pacific Coast Gypsum Company, of Tacoma, Wash., was extensively developed during last year. A wharf 2,000 feet in length extending to deep water, with rock bins of 1,000 tons capacity, has been built, and a railroad to the mine workings a mile from the shore completed. Rock bins of 1,500 tons capacity and a shaft house have been erected at the mine. At the lower workings a shaft 190 feet deep has been sunk, and from this two levels consisting of 600 feet of drifting have been extended, exposing

a deposit 150 by 200 feet in lateral dimensions, though no well-defined limits have yet been reached. At the upper workings, 800 feet to the west, investigations were made in 1905 by a 75-foot shaft and drifts almost entirely in gypsum, but no further work has been done.

Shipments from this mine began in May, and several cargoes of rock have been delivered to the plaster mill at Tacoma, where it is prepared for the market.

MARKET.

Gypsum is in much demand along the Pacific coast as wall plaster, fertilizer, and in the manufacture of cement. The Puget Sound market is supplied in large measure from the deposits in Kansas, Colorado, Wyoming, and Utah. The California market is supplied by local deposits and those in Nevada and Utah. Transportation from these points to the seaboard cities costs from $4 to $7 per ton, and the present market prices in these cities of first-grade gypsum products are as follows: Crude, $5 to $7 per ton; land plaster, $6 to $8 per ton; plaster of Paris, $8 to $11 per ton; wall plaster, $9 to $12 per ton.[a]

CEMENT.

The demand for cement all along the Pacific coast is rapidly increasing, but deposits of raw materials for this industry along the Alaskan coast are of little value. The reason for this, in the first place, is the high cost of the fuel necessary for its manufacture. The difficulty in obtaining efficient and cheap labor, as compared with the Puget Sound area and California, must also be considered, and the long haul necessary to the market is unfavorable to such an industry. To ship the cement rock as mined to a cement factory established somewhere near the point of coal supply and the market would be the most feasible mode of procedure; but to do this would bring little or no profit, as vast areas of cement rock are exposed in the proximity of all the larger cities and can supply the cement plants along the coast for many years to come.[b]

COAL.

The most extensive explorations for coal in southeastern Alaska have been at Kootznahoo Inlet and Murder Cove, on Admiralty Island, and at Hamilton Bay, on Kupreanof Island. At these localities the coal-bearing formations are Tertiary in age and made up of

[a] For descriptions of the gypsum deposits of the United States, introduced by a discussion on the geology, technology, and statistics of gypsum, see Adams, G. I., and others, Gypsum deposits of the United States: Bull. U. S. Geol. Survey No. 223, 1904.

[b] For a discussion of the distribution of cement materials and its industry in the United States, see Eckel, E. C., Cement materials and industry of the United States: Bull. U. S. Geol. Survey No. 243, 1905.

conglomerates, sandstones, and shales. The beds are all more or less faulted and appear to occupy basins formed in the more ancient rock beds. The coal is with few exceptions an impure lignite and occurs in narrow seams of no commercial value.

At Murder Cove explorations were made on a seam 5 feet thick, located 2 miles from deep water. This deposit, which contains the best grade of coal in the region, proved to be of very small extent and not worthy of further development. No developments have been made at any of the above localities and most of the prospects have been abandoned.[a]

[a] For a more detailed discussion of the coal deposits on Admiralty Island see Wright, C. W., A reconnaissance of Admiralty Island: Bull. U. S. Geol. Survey No. 287, 1906, pp. 151-154.

RECONNAISSANCE ON THE PACIFIC COAST FROM YAKUTAT TO ALSEK RIVER.

By Eliot Blackwelder.[a]

GEOGRAPHY.

The region explored in the reconnaissance which forms the subject of this paper lies in the northwestern part of the coastal strip of southeastern Alaska. Roughly the area is about 70 miles long parallel to the coast and extends from 5 to 20 miles back from it.

The most prominent feature of this coast is the steep-fronted range of mountains which extends in a nearly unbroken line from Yakutat Bay to Alsek River and beyond. This coastal range is comparatively low, averaging from 3,000 to 4,000 feet in elevation; but back of it rise serrate snowy ranges of greater altitude. North of or within the mountain front the valleys are filled with ice, so that the region is essentially an ice plateau, which is relatively level in the interior but descends about its edges in the form of protruding glacial lobes. Buried ranges of mountains projecting above this interior ice plateau form nunataks. The front range is separated from the ocean by a coastal plain, which varies from 6 to 15 miles in width. This foreland is without notable relief, except for a few low hills close to the base of the mountains and here and there sand dunes near the coast.

From Cross Sound to Copper River, a distance of more than 350 miles, only one valley penetrates back into the interior of the country, namely, that of Alsek River. This powerful stream rises in the interior plateau of the Yukon Territory and after traversing the coastal mountain belt in a series of narrow canyons emerges suddenly upon the foreland and flows into the Pacific through the divided channels of its delta.

GEOLOGY.

GENERAL STATEMENT.

The ages of the indurated rocks of this region have not yet been determined, but on account of their resemblance to formations in adjacent regions it is thought that they belong largely to the Paleozoic

[a] My associate, Mr. A. G. Maddren, deserves commendation here for his excellent service to the expedition, especially in his capacity as topographer.—E. B.

and perhaps in part to the early Mesozoic era. Two distinct series have been differentiated, and the existence of a third is suspected on the evidence of material brought out from behind the range by glaciers. The two oldest of these series are considerably metamorphosed. The youngest is but little altered. All of them have been intensely and complexly folded and have been broken by overthrusts and tension faults to such a degree that the structural features are most intricate.

FORMATIONS.

METAMORPHIC COMPLEX.

The material brought out from the area of the interior ice fields by the Yakutat and Alsek glaciers comprises a large variety of such metamorphic and igneous rocks as hornblende schist, greenstone, gneiss, marble, granite, diorite, and porphyries. No similar rocks were observed in place at any point in the Coast Range by the writer, and, as they are distinctly more altered than the two other series observed, it is believed that they belong to a still older group of formations.[a]

SCHISTOSE SEDIMENTARIES.

The lowest canyon of Alsek River exhibits a fine section of metamorphosed sedimentary rocks lying in vertical isoclinal folds. The section is incomplete at both ends and the relations of the rocks are as yet unknown. The portion of the series there exhibited consists largely of quartzose schists and phyllites—the metamorphic derivatives of alternating graywackes, quartzites, and slates. On account of the rapid alternations in the composition of the original deposits, the initial bedding of the rocks is still fairly distinct, and it happens that the schistosity is in most places parallel to this bedding. Throughout the exposure numerous small quartz veins and stringers traverse the schists. None of these, however, was found to contain valuable minerals.

YAKUTAT SERIES.[b]

The Yakutat series has been described in detail by several geologists[c] who have studied the rocks about Yakutat Bay. Subsequent exploration shows that the greater part of the Coast Range to the east, at least as far as the east side of the Yakutat Glacier, consists of

[a] From observations on the shores of Russell Fiord, Tarr infers that the green schists and gneisses are stratigraphically continuous with schistose graywackes and slates similar to the second series of the present paper (unpublished evidence, 1905).

[b] The use of the word series is not in accordance with the Survey rules of nomenclature, but is a temporary expedient only, to be abandoned as soon as sufficient detailed work is done to permit the subdivision of the rocks to which it is now applied.

[c] Russell, I. C., Nat. Geog. Mag., vol. 3, 1891, pp. 167-170. Emerson, B. K., Harriman Alaska Expedition, vol. 4, 1904, pp. 49-50, 125-146. Tarr, R. S., and Martin, Lawrence, Bull. Geol. Soc. America, vol. 17, 1906, p. 33.

the same rocks. The contact between this series and the older systems has not yet been discovered, but may be looked for near the head of Ustay River. East of that general vicinity the mountains are composed chiefly of the preceding series. The Yakutat rocks are distinguished from those previously described mainly by a general absence of the effects of metamorphism. The predominant rocks are graywackes and black clay rocks which are slates or shales according to locality. Many of the graywackes are conglomeratic, the conglomerates being internal rather than basal. The pebbles consist of black slate, dark graywackes, limestone, granite, schists, etc.

The stratigraphic succession within the Yakutat series was not definitely ascertained, for the structure of the beds is so complex as to defy analysis without detailed mapping. The writer's present interpretation of the structure suggests that the section is roughly as follows:

2. Slates or graywackes of black and gray color, with local beds of coarse and fine conglomerate. Some of the graywacke members are 200 to 500 feet thick.
1. Bowldery slates—black stratified rocks containing pebbles and bowlders of all sizes and various compositions.

Only the lower member of this section requires further mention. This bowlder deposit consists of black shale or slate in which stratification is usually distinct. Pebbles and bowlders are scattered through it without orderly arrangement. In size they vary from fine gravel to bowlders at least 100 feet in diameter; in composition they include varieties so widely different as granite, white limestone, greenstone, graywacke, and quartzite. Although irregular in form, the bowlders are generally roundish or subangular. They have not the well-rounded contours characteristic of waterworn stones. The general character of the deposit suggests that it may be an offshore formation over which floating icebergs strewed their débris at random.

Fossils are rare in the Yakutat series and are of unsatisfactory nature. Those found consist chiefly of jointed stemlike casts,[a] which may represent plants or possibly worm trails. None are of much value for purposes of correlation with the terranes of other regions.

GLACIAL DEPOSITS.

In view of the great development of glaciers, both now and in the last geologic epoch, it is, on first thought, rather surprising that more extensive deposits of drift are not found in the Yakutat region. The moraines along the east side of Yakutat Bay, stretching out to Ocean Cape, have been described by Tarr and Martin.[b] There appears to be another loop of drift concentric with the south end of

[a] For similar varieties see Ulrich, E. O., Harriman Alaska Expedition, vol. 4, 1904, pp. 125-146.
[b] Tarr, R. S., and Martin, Lawrence, Bull. Am. Geog. Soc., vol. 38, 1906, pp. 155-160.

Russell Fiord and extending eastward along the base of the range nearly as far as Anklin River. This moraine, with its hillocks and lakes, is believed to have been made by a glacier which formerly occupied Russell Fiord. The glaciers in the front range have left only small and relatively fresh moraines. At the foot of the Yakutat Glacier, the largest lobe of ice between Yakutat Bay and Alsek River, a broad, flat terminal moraine hems in a crescent-shaped lake, which in turn borders the present end of the glacier. This moraine has every appearance of being a comparatively recent deposit.

Aside from the deposits of till there is a vast amount of stratified glacial drift mingled with the strictly fluviatile sands and gravels of the coastal plain.

This alluvium of double origin forms much the largest part of the foreland.

RECENT ALLUVIUM.

The streams coming down from the front range, including the Alsek itself, are engaged in building a plain of sand, gravel, and silt out into the Pacific. The formation of salient deltas is prevented by the strong littoral currents, which sweep the finer detritus along the coast and out of it build bars and spits in favorable situations. To some extent the wind has formed low sand dunes along the coast, but the effectiveness of this process is reduced to a minimum by the dampness and the rapid growth of vegetation.

STRUCTURE.

The structure of the most ancient metamorphic series is not definitely known, but is confidently believed to be highly complex.

Both of the younger bed-rock series are intensely and intricately folded. The folds are as a rule isoclinal and in many places overturned toward the west. The strike of the folds is not everywhere parallel to the axis of the range, as it might be expected to be. Near the Yakutat Glacier it trends north-northwest, making an angle of 40° to 50° with the general axis of the mountains. On this account the individual folds come out successively into the plain and disappear; but as the crumpling is repeated over and over again in about the same plane, no older or younger formations are exposed. The details of structure exhibited by the slaty rocks are in many places extremely complex, but the massive layers of graywacke are more regularly flexed. The structural relation between the Yakutat series and the schistose strata on the Alsek was not determined. The marked difference in metamorphism between the two series is thought to imply that they are separated by an unconformity; if not, then the schists of the Alsek may be merely a more altered eastward extension of the Yakutat slates and graywackes.

PHYSIOGRAPHY.

The front range is a maturely dissected ridge, modified and sharpened in its details by recent glaciation. The valleys on the coastal side present distinct evidence of two cycles of valley development. The older cycle is indicated by shoulders on the spurs at an elevation of 1,200 to 1,500 feet; these are interpreted as representing the bottoms of broad valleys. Above the shoulders the average slope is not steep and the ample tributary gulches have occupied the entire field. Beneath the shoulders the more recent canyons belonging to the second cycle are intrenched. Along the front of the range a series of rocky terraces corresponds to and merges into the high shoulders just mentioned. Another and less continuous line of terraces and flat-topped hills of rock stands at an elevation of about 100 feet along the border of the mountain front. Both sets of benches are attributed to erosion by the waves of the Pacific when it stood farther inland than now.

The following summary of the physiographic history of the region conveys the writer's interpretation of the observed facts. It is presented as a suggestion for more detailed and critical work by future students of the region:

1. *Early erosion cycle.*—Mature dissection of a broad west-northwest uplift.[a] Formation of open main valleys with divides 1,000 to 2,000 feet high, and the production of broad marine shelves by waves cutting on the seaward front of the mountains.
2. *Canyon erosion cycle.*—Rejuvenation of drainage by an uplift amounting to about 1,200 feet. As a result the development of V-shaped canyons within the older valleys. In most places the rejuvenation has not yet reached the heads of the older gulches. Formation of high sea cliffs and low cut terraces on the outer spurs of the mountains.
3. *Glacial erosion cycle.*—Maximum extension of glaciers; excavation of cirques in the heads of the gulches. Ice mounted 1,200 to 1,500 feet higher on the slopes of the valleys than now, and was proportionately more extensive. Most of the large glaciers discharged into the ocean, which skirted the mountain front.
4. *Glacial retreat.*—Uplift of about 100 feet, resulting in the partial uncovering of the coastal plain. Yakutat Bay and Russell Fiord glaciers formed moraines upon the flat before retreating. Other glaciers probably receded before the ocean was excluded from their valleys, and consequently formed no moraines. Plain gradually extended by the deposits of shifting streams. The glaciers decreased to nearly their present size and many of them entirely disappeared.

PROSPECTING.

The district described has been explored to some extent by prospectors since the early nineties, but as yet no deposits of proved value have been discovered. The beach placers about Yakutat Bay have been described by previous observers.[b] Deposits of black sand on Black Sand Island contain small amounts of gold and have been

[a] From results of studies by Russell and by Tarr and Martin it seems probable that this is a rising fault block.

[b] Tarr, R. S., Bull. U. S. Geol. Survey No. 284, 1906, p. 64.

worked in a desultory way by several parties, but without material success. Prospectors who have explored the valley of the Alsek report finding "colors" at several points in the canyons. Aside from these somewhat unpromising occurrences there is no evidence of the existence of gold deposits in the district.

It is stated that there are green stains indicative of copper in the canyon of the Alsek just above the main forks; but nothing is known of the value of the deposit. The slates of the Yakutat series along the front range also contain abundant small nodules and stringers of iron sulphides which probably contain a small percentage of copper. A large vein of this mineral is reported to have been found last summer on the shore of Russell Fiord and a claim has been staked for the purpose of developing the property. Specimens of the ore appear to be chalcopyrite, and as the deposit is located at tide water it may become valuable if sufficiently extensive.

A large portion of the coastal plain east of Yakutat was staked out in oil claims some years ago, evidently on the supposition that it is similar geologically to the plain near Controller Bay. There is not, however, the slightest indication of the presence of oil-bearing rocks in the district, and the claims are now abandoned.

POSSIBLE ROUTES TO THE ALSEK VALLEY.

At present there seems to be no easy way of reaching and exploring the valley of Alsek River. Nevertheless, there are several routes which are feasible, although some of them are more or less dependent on the season of the year and the condition of the glaciers.

From Dry Bay.—Alsek River can be ascended in small boats from its mouth only in time of low water. In the months of June, July, and parts of May and August the lower canyon, 20 miles from its mouth, is usually impassable. At these times the river fills this canyon in the Coast Range from the front of the Alsek Glacier, which forms one wall of the canyon, to the precipitous cliffs of rock on the opposite bank. Although difficult, it is possible even under these conditions to drag boats up along the west bank; but the almost incessant falling of rocks from the cliffs renders such an undertaking eminently perilous. It is said that when the river subsides in the autumn a gravel bar is uncovered and boats may be hauled along this without special danger. Once above this canyon, the navigation of the river appears to involve no great difficulties—at least as far as the abandoned settlement of New Hamburg.

Across the glacier from Yakutat.—In 1898 parties of prospectors reached the Alsek by crossing the ice fields from Russell Fiord. They landed from boats in Northeast Arm and carried their outfits up the moraine of the south branch of the Nunatak Glacier. After reaching the bare ice they were able to sled their baggage about 40 miles, over to

the head of American River, a tributary of the Alsek. Some years later another party attempted to cross by this same route, but were unsuccessful on account of the badly crevassed condition of the glacier. Evidently the feasibility of this route depends on the state of the ice at the time the attempt is made.

It may also be possible to use the Yakutat Glacier in the same way and thus to shorten the distance of ice travel by at least one-half. From Yakutat a party can take boats to Dangerous River and ascend it to the east side of the lake at the foot of the glacier. The Indians say that from this point the interior ice field can be reached by traveling along the edge of the glacier. So far as the writer knows, the route has not yet been actually traversed by either natives or white man.

From Chilkat River.—Another route, which has the advantage of being well known, extends from Chilkat River over Dalton's trail as far as the head of the east branch of the Alsek. This stream is said to be navigable for river skiffs, although somewhat turbulent for ordinary canoes. The first explorers [a] of the Alsek descended this branch to the forks and then reached the coast by way of the main river.

By way of Whitehorse and Dezadeash River.—It is possible to go from Whitehorse to Dezadeash River over a wagon road recently built into the Kluane Lake mining field. Having reached the Dezadeash a party can easily descend by boat into the upper canyon of the main Alsek as far as the first glacier which comes into the river. It is said that this glacier forms a series of rapids which is entirely impassable, but that by making a portage of several miles across the end of the glacier it is possible to reach the river again below. From that point navigation can be resumed and continued to the Pacific.

[a] Glave, E. J., Frank Leslie's Illustrated Newspaper (weekly), vols. 70–71, June 28, 1890, to January 10, 1891.

PETROLEUM AT CONTROLLER BAY.

By G. C. Martin.

INTRODUCTION.

LOCATION.

The Controller Bay petroleum field is located on the north shore of the bay, which is a few miles east of the mouth of Copper River, in longitude 144° to 144° 40′ west, latitude 60° 10′ to 60° 15′ north. The localities at which there are known indications of petroleum are confined to a belt about 25 miles long from east to west and from 4 to 8 miles wide from north to south. (See fig. 1.) This belt is adjoined on the north in part by the Bering River coal field. Its southern border

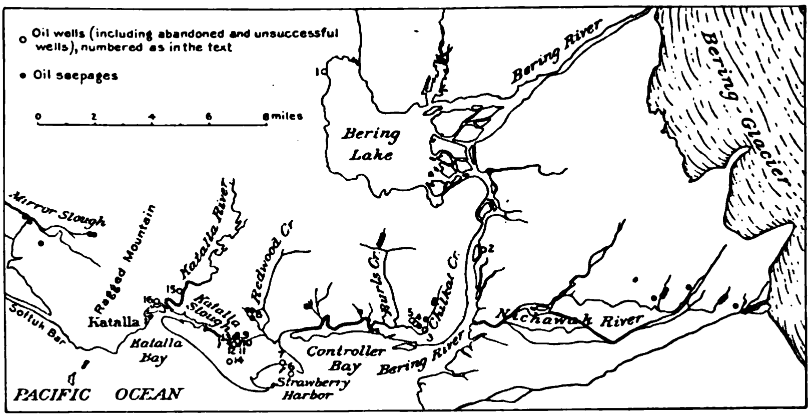


Fig. 1.—Map of Controller Bay oil field, showing position of wells and seepages.

is formed by Controller Bay and the Pacific Ocean and by the alluvial flats on the east shore of Controller Bay. The eastern and western terminations are formed by Bering Glacier and by the Copper River delta, respectively.

OUTLINE OF THE GEOLOGY.

The geology of the region and the occurrence of petroleum have already been described,[a] but more detailed geologic work and further developments have added much to the knowledge which was available

[a] Petroleum fields of Alaska and the Bering River coal fields: Bull. U. S. Geol. Survey No. 225, 1904, pp. 365–382. The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits: Bull. U. S. Geol. Survey No. 250, 1905, 64 pp. Notes on the petroleum fields of Alaska: Bull. U. S. Geol. Survey No. 259, 1905, pp. 128–135.

when these papers were written. A final report on the geology and mineral resources of the region is now in preparation. The present paper contains an abstract of such parts of that report as relate to petroleum.

The general stratigraphic sequence in this region is represented in the following table:

Generalized section of rocks in the Controller Bay region.

Age.	Character of beds.	Thickness.
		Feet.
Quaternary	Fluviatile, glacial, and beach deposits	0-500+
	Marine sands and clays	60
Tertiary	Shales, sandstones, conglomerates, and arkose	12,000+
Paleozoic or Mesozoic (?)	Slate and graywacke with interbedded or intrusive greenstone and other igneous rocks.	

The oldest rocks of the region are the slates and graywackes, with associated igneous rocks, which make up the mass of Ragged Mountain and the low hills west of it and constitute all but the southeastern extremity of Wingham Island. The observed contacts of these rocks with the Tertiary rocks are faults. The amount of metamorphism which these rocks have undergone as compared with the Tertiary rocks, which though in direct contact with them are entirely unmetamorphosed, proves a much greater age for the former and a great unconformity between them and the Tertiary rocks. The lithologic similarity of these older rocks to the Paleozoic or very early Mesozoic rocks at Yakutat, Orca, and Kodiak is suggestive of a corresponding age.

The Tertiary sediments consist of monotonous repetitions of shales and sandstones, with an included mass of coal-bearing arkose, and one or more massive conglomerates. The total thickness, as stated in the foregoing table, is at least 12,000 feet. The structure of the region in which these rocks outcrop is complex, exposures are wanting at many critical points, and neither the lithologic character of the beds nor the fossils which they contain are sufficiently distinctive to make it possible to recognize with certainty the complete stratigraphic succession.

The presence of two easily recognized kinds of rock, the arkose and the conglomerate, gives distinctive character to two parts of the stratigraphic column. The arkose is restricted in areal distribution to the region north of Bering Lake, and the conglomerate to the region south of the lake. Between these regions are areas of no outcrops, and none of the beds of either region can be recognized with certainty in the other. The following sections represent the rocks north and south of the lake:

Section north of Bering Lake.

	Feet.
a. Sandstone	500
b. Shale with thin flaggy sandstones and with occasional calcareous concretions	2,000
c. Arkose with many coal beds and with some shale and sandstone[a]	3,000
d. Shale and sandstone	1,000+

Section south of Bering Lake.

	Feet.
e. Conglomerate and conglomeratic sandstones interbedded with shale and flaggy sandstones	3,000
f. Soft shale with calcareous concretions and with a bed of glauconite near the base	2,000
g. Sandstone	1,000
h. Soft shale	500

The succession in each of these sections may be assumed as reasonably correct, although there is a possibility that the thicknesses are too great because of the repetition of the less characteristic beds by faulting. The correlation of the beds of one section with those of the other rests at present on evidence which is incomplete and unsatisfactory and must be regarded as suggestive rather than proved. It is probable that one of two correlations is true. The shale and sandstone (*d*) may overlie the conglomerates (*e*), with a concealed interval of unknown extent between them; or *a* and *b* may be identical with *g* and *h*. In the former case the conglomerates underlie the coal field; in the latter case the coal underlies all or nearly all of the entire region under discussion. The stratigraphic and structural field evidence proves nothing either way, but suggests, as the most probable relation, that the entire section north of Bering Lake overlies the section south of the lake.

The Quaternary deposits form the surface of practically all the low flats of the entire region. They fill all the large valleys to a considerable depth, which in one place is known to exceed 500 feet.

DEVELOPMENTS.

Active attempts to produce petroleum in commercial quantities in this region have been made for the last five years. The first well was begun in the summer of 1901, but no oil was produced and no great depth was reached, as the tools were soon lost and the well abandoned. The next year the same people drilled another well and obtained some oil. Six wells were being drilled in 1903. The following year witnessed the greatest activity that the region has seen, eight wells being in progress. In 1905 and 1906 operations were restricted to two wells.

The result of these operations has been to obtain one well which yields a moderate amount of oil, another well which is capped, but in

[a] The Kushtaka formation of earlier reports.

which the oil has at times a considerable pressure, and two more wells in which an unknown amount of oil stands near the top of the casing.

Drilling has proved to be very difficult and expensive and the results are not as encouraging as had been hoped. These facts, together with the uncertainty as to the amount of territory which one concern may legally control, and the equally great uncertainty as to the conditions of the market, have led to a suspension of some of the more active operations.

The petroleum obtained in the region, both from the seepages and from the wells, is all a high-grade, light-gravity, refining oil, with paraffin base and high content of naphthas and burning oils. The character of the oil has already been described[a] by the writer and no new information is available.

OCCURRENCE OF PETROLEUM.

SEEPAGES.

GEOGRAPHIC DISTRIBUTION.

It may be seen from inspection of the map (fig. 1) that the seepages all occur within a long, narrow belt extending from the edge of the Copper River delta to Bering Glacier, a distance of about 28 miles from east to west. The belt is very narrow, not exceeding 4 miles at the widest known point, and is parallel to the north shore of Controller Bay, which has the same east-west direction as the larger aspect of the shore of the Pacific Ocean between Copper River and Yakutat Bay. The seepages at Cape Yaktag[b] are also reported to lie on a line having the same direction as this and practically coinciding with it in extended position. Several of the smaller groups of seepages, such as the group on Redwood Creek and at the head of Katalla Slough, and those in the valleys of Burls and Chilkat creeks, and in the Nichawak region, have a distinct linear arrangement, each extending in a direction of about N. 15° E. These lines coincide with the directions of the valleys in which they occur, and the relationship suggested is that either the position of the valley and that of the line of seepages are due to the same cause or that the former is the cause of the latter.

RELATIONS TO KINDS OF ROCKS.

The oil of the seepages reaches the surface through a variety of rocks. (See pp. 93–95.) The seepages west of Katalla are associated with metamorphic rocks, the oil coming to the surface either through the joints and bedding or cleavage planes of the slate and graywacke or through surficial deposits which probably overlie such rocks. The

[a] Bull. U. S. Geol. Survey No. 250, 1905, pp. 57-58.
[b] Locally known as Cape Yakataga.

presence of petroleum in rocks of this character is somewhat unusual and worthy of notice. Similar occurrences of small quantities of oil in metamorphic rocks are known in California and Washington, where the oil is considered to have migrated into the metamorphic rocks subsequent to their alteration. A similar explanation may account for the Alaska occurrence. The writer would suggest as a possible explanation that the metamorphic rocks, which are known to be separated from the Tertiary shales by a fault, are overthrust upon the shales along a fault plane of low hade, and that the oil at the seepages west of Ragged Mountain is coming through the metamorphic rocks from underlying shales.

The seepages at the head of Katalla Slough and on Redwood, Burls, and Chilkat creeks are all in the soft shales, which have previously been called the Katalla formation (*f* of section on p. 91). Those between Redwood and Burls creeks are associated wth conglomerates of presumably higher position (*e* of the section). Such of the seepages of the Nichawak region as have been seen by the writer are in shales which closely resemble those referred to above. The Cape Yaktag seepages are said to be in Miocene sandstones and shales.

RELATION TO THE STRUCTURE.

The position of the seepages with reference to the structure is somewhat vague and uncertain. Those west of Katalla are on steeply folded rocks in which the structural features have not been determined. The group on Redwood Creek and Katalla Slough is apparently in close proximity to a fault. The Burls Creek and Redwood Creek groups are each near the axis of an anticline, the Redwood Creek anticline being probably broken near or west of its axis by a fault. The seepages between Burls and Redwood creeks are on monoclinal conglomerates. The general structure of the Nichawak region has not been determined, but the rocks have steep dips and are probably closely and complexly folded. The Yaktag region, which has not been visited by the writer, is said to have an anticline near and parallel to the coast, north of which the rocks have a monoclinal northward dip. The seepages are said to occur on the north flank of the anticline, parallel to and not far from its axis.

DESCRIPTION OF THE SEEPAGES.

Petroleum seepages and gas springs are very numerous in many parts of the oil belt, and at some of them the flow of oil or of gas is large.

Several large oil seepages were seen by the writer on the banks of Mirror Slough, near the mouth of Martin River. The petroleum comes to the surface from the clay and mud of the valley floor, and a large amount has accumulated in the pools on the swampy surface

and in the soil. The nearest outcrops of hard rock are sandstones or graywackes, probably the same as those on Wingham Island and in Ragged Mountain, and if so of pre-Tertiary age. It seems almost certain that the oil came from these rocks. Seepages were also seen near the head of Mirror Slough at the base of Ragged Mountain. The oil here reaches the surface from the soil, which is underlain either by glacial drift or by talus or landslide débris. The underlying rocks are probably the slate or graywacke referred to above. Another seepage about 1 mile south of this point, in the canyon immediately north of Bald Mountain, was visited by the writer. The oil was here seen oozing in small quantities directly from the joints and bedding planes of the steeply dipping slates and graywackes.

Oil is reported to have been seen in large amounts at the time of the earthquake in September, 1899, on the surface of the water of the small ponds and the creek at the south end of Katalla. The surface material consists of rock débris, largely from Ragged Mountain, underlain by the soft shales previously described as the Katalla formation.

Numerous and copious seepages are to be seen at the head of Katalla Slough. The oil impregnates the soil very completely at many points and has accumulated in large amounts on the surface, but these accumulations are chiefly of oil and are not residues, as at the California brea deposits. No outcrops are near, but the underlying rock is almost certainly the soft shale referred to above, and probably has a steep dip.

On the west slope of the valley of Redwood Creek, about 1½ miles northwest of the mouth of the creek and near a well, oil can be seen coming directly from soft fissile iron-stained shales. The shale has been broken into small angular fragments and recemented by ferruginous material. This condition is common at or near seepages in these shales, but we do not know whether it is a surface condition connected with erosion or whether it indicates crushing of the rocks at a depth below the surface during the process of folding or faulting. Here, as at many other seepages, sulphur springs are associated with the oil. Another seepage was seen near the headwaters of Redwood Creek.

It is reported that oil may be seen at low tide in the beach sands on the north shore of Strawberry Harbor. The rocks in the vicinity are sandstone and shale, probably belonging much higher in the stratigraphic column than the soft shale at the seepages previously described.

There are several seepages along the wagon road which leads from the head of Katalla Slough to the mouth of Bering River. Two of them are located about a mile and a half west of Burls Creek and close to the road. The amount of oil at one of these is large. The

nearest visible rock is steeply dipping conglomerate, which outcrops a few feet away, but the oil can be seen only on the surface of the soil, the direct source not being visible.

The upper part of the valley of Burls Creek contains many seepages at which the oil oozes directly from steeply dipping shales that here contain a large amount of glauconitic grains, making the rock green. Large calcareous concretions are abundant, and many of them take the form of septaria nodules with calcite fillings. Organic remains are frequently seen in the concretions. The soft shale is also rich in organic material, some beds being so dark as to suggest in appearance impure coal. No coal was seen by the writer in the vicinity or anywhere else in these rocks. The rocks seem to be very strongly impregnated with oil in this locality and seepages are numerous, but large surface accumulations are rare. Broken shale recemented by ferruginous material was seen here as on Redwood Creek.

Some seepages with considerable surface accumulation of oil were seen along the edge of the tidal flat close to the wagon road halfway between Burls Creek and the mouth of Bering River. Outcrops were absent in the immediate vicinity, but fragments of shale indicated the presence of such rock.

Several seepages have been reported from Chilkat Creek. The largest one seen by the writer is in the west bank of the creek, 1½ miles above the forks of the wagon road. The oil reaches the surface through soft brecciated shale with a steep westerly dip. The seepage is associated with a black sulphur spring.

Many seepages have been reported in the group of hills centering around Mount Nichawak. Those seen by the writer were small, but the oil issued directly from the rock, which is shale resembling that at the seepages west of Bering River. Others are reported to be located on the banks of a small lake that is said to be covered at times with oil.

Other seepages have been reported from various parts of the Controller Bay region, but they have not been seen by the writer. Reference should be made to those in the vicinity of Cape Yaktag, about 75 miles east of Controller Bay. The amount of oil is said to be very large, the flow being continuous from several of the seepages, one of which has been estimated to yield several barrels of oil per day. The oil is said to come directly from the rocks, which are shales and sandstones of Miocene age, and to come from a line of seepages located along the crest of an anticline parallel to the coast.

Inflammable gas comes to the surface of the water in large amounts in several places. The largest of the "gas springs" seen by the writer are in Mirror Slough and in Katalla River. The former is sufficient to furnish a large continuous flame. The composition of the gas is not known. It issues from the mud on the bottom of the slough.

POSITION AND DESCRIPTION OF WELLS.

The wells in which oil has been obtained in this region are so few that they throw little or no light on the problem of the occurrence of oil. It will be shown in the following pages that a flow of oil has been obtained in one well (No. 10, fig. 1) and less quantities in three others (Nos. 5, 8, and 13). These four wells are close to seepages and are on the outcrop of the shales which have been referred to as the Katalla formation. They are all on lines of seepages having a north-northeast to south-southwest direction, and are all on the steeply dipping northwest flanks of anticlines and possibly on or near lines of faulting. It is unfortunate that no other wells have been drilled in similar positions on the structural lines alluded to above. Such wells might not be successful, but they would test the possible theory that the above-mentioned lines have something to do with the distribution of the oil.

The net result of the drilling has been to show the existence of moderate amounts of oil in at least part of the territory. The wells are neither numerous enough nor deep enough to determine the outline of the pools and the area of productive territory. They have demonstrated the difficulty and expense of drilling and the need of ample resources and careful management. The existence of oil in remunerative quantities has neither been proved nor disproved. The evidence from the existing wells, like that of the seepages, is sufficient to warrant further testing, if it be done intelligently and carefully and by companies strong enough to exploit large areas on a scale which permits of wholesale economies, and also strong enough to risk their capital on what must certainly be regarded as a speculation rather than an investment.

The following list contains an account of each well that has been drilled in the district. The numbers refer to the geographic location of the wells, as shown on the accompanying map (fig. 1, p. 89).

1. West shore of Bering Lake. The surface rocks are sandy shales, presumably underlying the coal-bearing rocks. Dip 12° to 35° NW. Well begun in 1905. Work interrupted by accidents to machinery. Depth several hundred feet.

2. East shore of Bering River. Begun in 1903. Abandoned at depth of 580 feet without reaching bed rock because of difficulty of sinking casing through the mud.

3. Chilkat Creek. Drilled in 1904 to a depth of several hundred feet. No information available.

4. Edge of tide flats 1 mile west of mouth of Bering River. Drilled in 1904 to a depth of several hundred feet.

5. Edge of tide flats a short distance northwest of No. 4. Drilled in 1904 to a depth of several hundred feet. Oil now stands near top of casing. Small but continuous flow of gas. Amount of oil not known.

6. Strawberry Harbor. The derrick was built on piling about 1,000 feet offshore. Casing sunk deep into the mud in 1904 without reaching bed rock.

7. Strawberry Harbor. Drilled several hundred feet in 1904 without obtaining oil.

8. Redwood Creek. Drilled to a depth of several hundred feet in 1904. Oil now stands about 20 feet below the top of the casing. Quantity not known.

9. Near head of Katalla Slough. Drilled to an unknown depth in 1904. No oil, so far as known.

10. Near head of Katalla Slough. Drilled in 1902 to a depth of 366 feet, where a flow of oil was obtained. Drilled to 550 feet in 1903 without further results. In 1904 this well was pumped for fuel at the other wells of the same company. It is now capped, the oil oozing around the casing.

11. Near head of Katalla Slough. Drilled in 1901 and abandoned because of loss of tools.

12. Near head of Katalla Slough. Drilled in 1903 to an unknown depth.

13. Near head of Katalla Slough. Drilled in 1904 to an unknown depth. Now capped, the oil squirting at times in strong jets from the casing.

14. Between head of Katalla Slough and Cave Point. Drilled in 1903 to 1,710 feet and abandoned because limit of outfit was reached.

15. Katalla River. Casing sunk to a depth of 280 feet in 1903 without reaching bed rock.

16. Near Katalla. Two holes have been drilled in 1904 to 1906 on this site, a depth of about 1,500 feet having been reached. Work is still in progress.

PRINCIPLES GOVERNING THE OCCURRENCE OF PETROLEUM.

The four great problems of the geologic occurrence of petroleum are the origin of oil, the movements of oil in the rocks, the stratigraphic and structural distribution of the existing accumulations of oil, and the determination of the location and area of valuable accumulations from the known facts of surface geology.

These problems are stated above in the order of increasing importance from the point of view of immediate utility. The last problem can be solved in either of two ways—by expensive practical testing with the drill or by the solution of the first and second problems, together with a complete and accurate knowledge of the areal geology of the region in which the occurrence of oil is suspected. In the present condition of our knowledge the practical method is the only certain solution of this problem. But all knowledge gained in this way, as well as all facts concerning the geology of the oil-bearing rocks, leads us nearer to the solution of the other problems, and hence hastens the time when we can determine within reasonable limits the presence of oil from our knowledge of the manner in which oil originates and accumulates. The first and second problems are consequently the problems of greatest ultimate importance and should, in a public geologic investigation, be given at least equal weight with the other or immediate commercial problems.

Petroleum occurs in rocks of practically all ages from the oldest Paleozoic to the Recent. All known productive bodies of oil are in rocks of sedimentary origin, such as sandstones or sands, shales or clays, limestones, and conglomerates. Minute quantities of oil have, however, been seen in volcanic or other crystalline rocks.

The origin of petroleum may be explained according to one of two theories. The oil may be of organic origin, having been derived from animal or vegetable matter which was associated with the mineral constituents of the rocks at the time they were deposited, or it may be of inorganic origin, having been formed by the chemical action of water on the formerly unoxidized mineral constituents of the rocks. The prevalent scientific opinion is in favor of the organic theory for the origin of the larger and more widespread accumulations of petroleum.

The movement of petroleum in the rocks is controlled by four factors—the direct action of gravity, capillary attraction, the presence of water, and gas pressure.

The effect of the direct action of gravity is to cause oil to go down as far as the rocks are porous, dry, and not too warm for the oil to exist as such. It will sooner or later be stopped in this downward movement by an impervious stratum (either a bed of close-textured rock or a bed filled with water), and will then move laterally along the upper surface of that stratum to its lowest point, where it will accumulate.

The effect of capillary attraction is to cause the oil to be diffused throughout the rocks in all directions, provided the rock is dry and of the right texture to permit capillary movement. The directions in which it will move will be controlled by the distribution of porous rock and will be modified by the other factors here discussed.

The presence of water causes an upward movement of the oil. The essential conditions for such movement are a porous rock containing both water and oil and a lower limit beyond which the water can not go. The water, because of its greater density, seeks a lower level than the oil and forces it upward until either the demand of all the water for space is satisfied or the oil is checked in its upward movement by an impervious stratum. In the former case the oil rests on the surface of the water in a state of equilibrium; in the latter case it is confined under pressure with a potential upward force.

Gas pressure tends to drive the oil in any unblocked direction. The requisites for oil movement caused by gas are the presence of gas, either in a contiguous body to the oil or being given off from or within the oil, and an impervious bed above the gas through which it can not pass. The gas then tends to accumulate on the upper surface of the oil and to force the oil downward in the direction of least resistance, which may either be vertical or have a lateral component. The oil would already have been in the lowest available space, and so further downward motion implies the displacement of water. The motion continues until there is equilibrium between the expansive pressure of the gas and the hydrostatic pressure of the water. The

oil is then confined between these forces and will escape under pressure at the first opportunity.

The most favorable conditions for the occurrence of petroleum over large and regular areas are the following:

1. A large and widely distributed original source of oil-yielding material.
2. Thick, extensive, and regular porous beds in which the oil can move freely and accumulate.
3. Impervious beds above and below the porous beds.
4. Small angles of dip and fairly regular structure.
5. Absence of deep fracturing or of irregularities of structure.
6. Absence of water in the rocks if the oil-bearing beds are synclinal; or presence of a moderate amount of water if they are anticlinal.

Such conditions are favorable to the occurrence of petroleum in large, regular, and easily outlined pools, to moderately large production and long life of the wells, and to a large degree of certainty in oil prospecting.

These conditions probably nowhere exist in their entirety, at least not over any broad area. Some of the Mississippi Valley and Appalachian oil fields come nearer to satisfying these conditions than any others in North America. It is very evident that few of these conditions are met in the Controller Bay region, and therefore nothing will be gained from further comparison with regions in which simple structure predominates.

Some of the California, Wyoming, and Colorado oil fields are characterized by complex and broken structure, in this respect being not unlike the Controller Bay region. These western fields show that it is possible for large accumulations of oil to exist in rocks with steep dips, irregular folds, and large faults. They show that the structure does not make it impossible for oil to exist in quantity in the region under discussion, but they show also the difficulties of drilling and of locating the pools in such a field, and demonstrate very clearly the need of careful operating and the risks which are necessarily involved.

OUTLOOK FOR PROFITABLE EXPLOITATION.

PROBLEM OF LOCATING POOLS.

If oil is found in quantity it will almost certainly be in circumscribed areas, and the location and boundaries of these areas will be of the utmost importance in the development of the field. The position, size, and shape of these productive areas can not be foretold in advance of all drilling or at the present stage of development. The wells which have been drilled in this region are so few, most of them are so shallow, and so little oil has been obtained that they give almost no light on the occurrence of oil in the rocks. But if at least one area were outlined wholly or in part by the known position of productive

and nonproductive wells it would then be possible to determine the relation of the occurrence of the oil to the geology and from the known facts of the geology to outline other possible productive areas in advance of drilling. For this reason it is of the utmost importance to obtain complete and accurate records of all wells, and to use the information and experience thus gained in locating subsequent wells.

DIFFICULTIES OF DRILLING.

CROOKED HOLES.

Much difficulty has been encountered in keeping the wells vertical, and delay and expense have resulted from the necessity of frequently reaming out the holes in order to straighten them. The crooked holes are the natural result of the steep inclination of the beds, with frequent alternations from hard to soft rocks. Whenever the drill passes from a soft rock to a harder one dipping at a steep angle the drill tends to be deflected and a crooked hole results. This difficulty will always be encountered in this region and will increase the time and cost of drilling. It will, however, become less as the knowledge of the local conditions becomes greater, for the tendency of the drill to deflect can be lessened by drilling slower when the deflecting bed is struck and by special shaping of the tool, and the holes can be straightened more quickly when the drillers have had more experience in the region.

CAVING.

When a well in soft or fractured rock stands uncased too long, the rock caves in, often burying and frequently causing the loss of the tools, and sometimes it is necessary to abandon the well. Much delay has been caused in this way at most of the local wells and it has added greatly to the cost of drilling. It has been impossible on this account to drill several of the wells as deep as they would otherwise have gone. The only remedy is to case the well at the proper time, and when the drillers know better the rocks with which they are dealing they will be able to anticipate the caving and introduce casing at the time when it is needed. Conditions may in this way be expected to improve in the future, and thus the cost will become less and the speed greater and it will be possible to sink wells to greater depths.

WATER.

The rocks of this region are full of water, and consequently large amounts are encountered in all the wells. This is undesirable for two reasons—the pressure of the column of water in the well keeps the oil back in the rocks and prevents it from coming out into the well, and the water reduces the effective weight of the drill and acts as a cushion

between the drill and the rock, in both ways reducing the power of the blow. The only remedy is in casing off the water, which can not be done too often without reducing the size of the hole to undesirable dimensions and finally limiting the depth to which it can be drilled without pulling the casing and going back and reaming out the hole.

REMOTENESS FROM SUPPLIES.

The remoteness of this region from a base of supplies increases the cost of labor and of freight, which will be discussed under a subsequent heading, and also increases the time and expense of drilling, by making it necessary either to carry an exceptionally large equipment of fishing and repairing tools and of general supplies or to be subject to delays in ordering special tools from a long distance. Conditions will improve in this respect with better facilities for communication and transportation, and can also be bettered if machine shops and supply depots are established, as they will be if the presence of productive oil territory is shown.

INEXPERIENCE WITH LOCAL CONDITIONS.

The difficulties caused by the lack of experience of the drillers with the rocks of the local section have already been alluded to under various headings. They may be summarized as including failure to drill slowly or dress the tools so as to avoid deflecting the drill on hard, steeply inclined surfaces; failure to note the crookedness of the hole and remedy it promptly; ignorance of local caving strata and consequent failure to case in time to prevent cavings; and failure to obtain proper and adequate outfit and supplies.

COST OF LABOR AND TRANSPORTATION.

The cost of drilling has been very largely increased over what it would be in more favored and better established oil fields by the high cost of labor and of transportation of men and freight. Not only are the drillers paid higher wages than they would receive at most localities, but the unskilled labor receives excessive pay. It is highly probable that when conditions become more settled and work is done on a larger and more permanent scale wage conditions will become more normal and transportation charges will be reduced.

SHIPMENT AND MARKETS.

If petroleum is produced in commercial quantities at Controller Bay a new set of problems concerning its disposal will arise. All the petroleum of the region, as far as is now known, is a refining oil of high grade, for which there is a good demand on the Pacific coast. The content of extremely volatile constituents, such as gasoline, is so

great that it is questionable whether the oil can be safely shipped in bulk without some refining. There are plenty of good sites for refineries at no great distance from the wells. If a harbor in the vicinity of Katalla or elsewhere on Controller Bay is utilized it will be a very simple matter to transport the oil from the wells to the wharves by short pipe lines on a practically level grade. If no harbor in the immediate vicinity can be used it will be necessary to ship from Orca Bay or elsewhere on Prince William Sound, a distance of about 80 miles westward and across Copper River. The grades to Orca are almost nothing and there will be no difficulties except in crossing Copper River. The distances from Katalla and from Orca to Seattle by the steamer route, "outside way," are about 1,250 and 1,350 statute miles, respectively.

CONCLUSIONS.

The geographic conditions are such as to cause heavy initial expense of prospecting and drilling, but admit of permanent improvements which will make these conditions much better without great engineering difficulties or excessive cost.

The geology is complex and difficult to interpret and does not show definitely the relation of the occurrence of the petroleum to the stratigraphy and structure. The known facts of the local geology are unfavorable to the presence of productive bodies of oil, and indicate that if oil is found in quantity the distribution of the productive areas will be very irregular and difficult to locate.

The surface oil showings (seepages), though widespread and copious, are not conclusive evidence of the occurrence of productive oil pools. They are apparently more promising than any other known facts in regard to the region would indicate. The only safe conclusion to be drawn from them is that they indicate the possibility of productive oil areas in the vicinity.

Operators and investors who may not be familiar with local conditions will do well to be governed by the following suggestions:

1. They should be certain that legal title can be obtained to a sufficient area to make it possible to sink many test wells under widely different conditions, and to expect a large enough probable production to pay for heavy initial expenditures and large permanent improvements.

2. They should have large enough capital to be able (*a*) to purchase in quantity and at low rates; (*b*) to build good roads and other improvements and thus reduce the cost of operating; (*c*) to carry a large stock of tools and supplies in order to avoid costly delays in drilling and to be able to drill deep; (*d*) to procure the best professional advice and good drillers; (*e*) to drill many test wells without hope of immediate profit; (*f*) to market the product in the face of the existing

conditions in the petroleum industry; and (*g*) to afford to lose the investment.

3. The first wells should be located on the strike and at no great distance from producing wells, or down the dip from a good seepage and at such varying distances that the rocks outcropping at the seepage will be encountered at depths ranging from a few hundred feet to the limit (in depth) of drilling.

4. Subsequent wells should be determined in position by the location of existing wells and by the structure. They should be along the strike and close[a] to productive wells, and either not along the strike and at a short distance or on the strike and at a considerable distance from nonproductive wells.

5. Drillers and tool dressers should be obtained from regions where there is difficulty in keeping the holes straight.

6. If oil is obtained it will probably be down the dip rather than up the dip from a seepage, in shallow wells near a seepage, or in deeper wells farther from a seepage.

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[a] The distance should vary with the porosity of the containing horizon.

RECONNAISSANCE IN THE MATANUSKA AND TALKEETNA BASINS, WITH NOTES ON THE PLACERS OF THE ADJACENT REGION.

By SIDNEY PAIGE and ADOLPH KNOPF.

INTRODUCTION.

In the following pages are presented the salient features of the geography and geology of a roughly quadrangular area lying adjacent to and northeast of Cook Inlet. The features of direct economic interest will be emphasized here, but the more complete discussion of the geology will be reserved for a fuller report now in preparation. The detailed report will contain a topographic map on a scale of 4 miles to the inch. This same province has been the subject of investigation by Mendenhall,[a] who explored the Matanuska Valley in 1898, and by Eldridge,[b] who explored the Susitna Valley in the same year. In 1905 Martin[c] made a brief study of the Matanuska coal field, which contains the most important of the mineral resources of the province thus far developed. Appended to the present report is a brief account of the more important developments in the placer districts of the adjoining regions.

GEOGRAPHY.

The area studied (see fig. 2) lies partly within the Talkeetna Mountains and partly within the valley of Matanuska River. The Talkeetna Mountains are separated from the main Chugach Range, of which they may be considered a part, by the Matanuska Valley. The Chugach Range trends westward from Mount St. Elias, turns southward at the Matanuska, and forms the eastern mass of Kenai Peninsula. Within the region of the Talkeetna Mountains the peaks rise to a general elevation of 5,000 to 6,000 feet, though altitudes of 8,000 to 9,000 feet are reached in the center of the range.

[a] Mendenhall, W. C., A reconnaissance from Resurrection Bay to Tanana River, Alaska, in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 265-340.

[b] Eldridge, G. H., A reconnaissance in the Sushitna basin and adjacent territory, Alaska: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 1-29.

[c] Martin, G. C., A reconnaissance of the Matanuska coal field, Alaska: Bull. U. S. Geol. Survey No. 289, 1906, 34 pp.

Matanuska River rises on the western margin of the Copper River plateau, flows westward and southwestward between the Talkeetna Mountains and the Chugach Mountains, and enters Knik Arm at its eastern end.

The Talkeetna Mountains are roughly divided into two sections by the drainage of Chickaloon Creek and Talkeetna River. The former heads in a glacier and flows southward for about 30 miles, entering the Matanuska about midway in its course. Talkeetna River rises on the northern side of the Chickaloon Creek divide and flows northwestward and southwestward to Susitna River.

The western portion of the region delimited by this division is characterized by a radial drainage, the great majority of the streams therein flowing away from the center of the area. In the eastern portion the drainage is divided between Matanuska and Copper rivers by a northwestward-trending watershed. The recent drainage has incised many steep-walled canyons, and progress, except along the larger river systems, is exceedingly difficult.

GENERAL GEOLOGY.

STRATIGRAPHY.

The rocks of the area investigated display considerable variety, both of age and of character, ranging from highly crystalline mica schists of unknown age to unconsolidated Pleistocene stream and glacial gravels. The following section shows, provisionally, the stratigraphy of this area:

Provisional statement of stratigraphy of Matanuska and Talkeetna basins.

Age.	Character.	Thickness.
		Feet.
Pleistocene	Stream and glacial gravels	300+
Unconformity.		
Post Eocene	Basaltic lavas, breccias, and tuffs	1,000+
Unconformity.		
Upper Eocene (Kenai)	Coal-bearing shales, sandstones, and conglomerates	3,000±
Unconformity.		
Lower Cretaceous	Limestone	300
Upper Jurassic and upper middle Jurassic.	Shales, sandstones, conglomerate, tuff, and arkose	2,000±
Unconformity.		
Lower middle Jurassic	Graywacke, shales, sandstones, and conglomerate	1,000±
	Greenstones, tuffs, agglomerates, and breccias	1,000+
(?)		
Upper Paleozoic(?). (Sunrise series)	Graywackes, slates, arkose, and greenstones	(?)
Upper Paleozoic(?). (Susitna slates)	Slates and graywacke slates	(?)
(?)		
Pre-Silurian(?)	Garnetiferous mica schists, albite-zoisite schists	(?)

The distribution of the above rocks has been indicated in a broad way on the accompanying map (fig. 2). On account of its small scale a condensation of the stratigraphic column was found necessary. An effort has been made, however, to bring out with greater

clearness the facts of possible economic importance. The rocks have been grouped as follows:

1. *Granitic rocks, chiefly quartz diorites.*—These are probably intrusive in rocks as high up in the stratigraphic column as the lower middle Jurassic. They apparently make up the main mass of the Talkeetna Mountains, and occur as isolated bosses on the south side

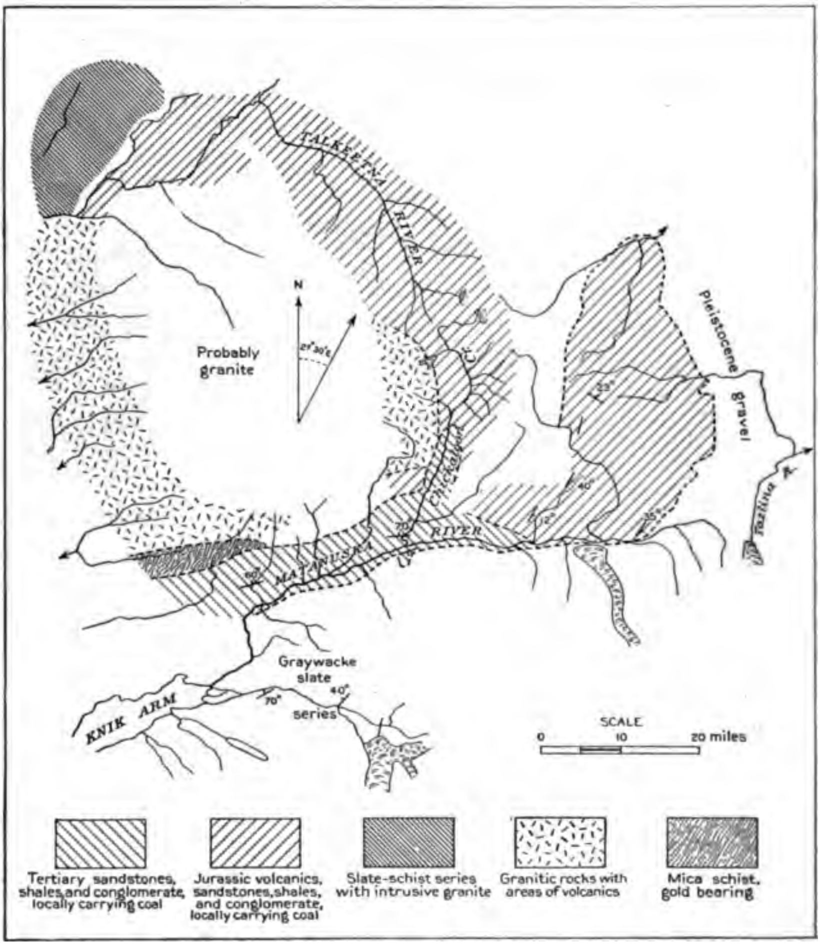

FIG. 2.—Geologic sketch map of region northeast of Cook Inlet.

of Knik Arm. The importance of these granitic rocks lies in the possible mineralization which they may have induced in adjacent formations as a result of "eruptive after-effects." Such a causal relation between intrusion and mineralization has been recognized by Spencer[a] in the case of the Coast Range granites of southeastern Alaska and by Lindgren[b] in California.

[a] Spencer, A. C., Magmatic origin of vein-forming waters in southeastern Alaska: Trans. Am. Inst. Min. Eng., vol. 36, 1906, p. 364.

[b] Lindgren, W., Characteristics of the gold-quartz veins in Victoria: Eng. and Min. Jour., 1905, p. 460.

2. *Mica schists.*—A narrow belt of these rocks borders the granites on their southern side. On account of their strongly foliated and thoroughly metamorphosed character they are regarded as representing the oldest rocks of the region. They possess considerable economic interest from the fact that locally they yield gold-bearing gravels, in places rich enough to be of commercial value.

3. *Slates and graywacke slates.*—These rocks occupy an area near the mouth of Talkeetna River and probably extend up Susitna River. They are known to be more or less gold bearing and have yielded some creek and bar diggings. On account of the lack of fossil evidence the age of these rocks is not known. They show some similarity to the series to be described next.

4. *Graywacke-slate series, including some greenstones.*—These rocks occur on the south side of Knik Arm, and are found striking into the Chugach Mountains on the south side of Matanuska River. They are a continuation of the rocks exposed in the Sunrise district on Turnagain Arm. No fossils have yet been found in them, so that their age is in doubt. They strongly resemble the rocks of Prince William Sound and are regarded by Mendenhall and Moffit as of probable upper Paleozoic age. The slates and graywackes are partially schistose and have been closely folded, uniformly presenting isoclinal dips. They are cut by a great multitude of small quartz stringers, and it is possible that these rocks may yet be found the source of gold placers.

5. *Jurassic.*—All the rocks of Jurassic age have been grouped together on the map. With them is included the lower Cretaceous limestone, whose distribution is limited to the headwater region of Matanuska and Nelchina rivers. These beds contain thin seams of low-grade bituminous coal. This is in marked contrast to certain localities in the Tertiary (Kenai) rocks, where strong seams of high-grade bituminous coal occur, a reversal of the usual state of affairs, in which the older rocks ordinarily carry coal of a higher grade than the younger rocks. In general the Jurassic rocks show only folding of an open character, but minor faulting is of widespread occurrence.

6. *Upper Eocene (Kenai).*—Strata of this age comprise a series of sandstones, shales, and conglomerates, carrying workable seams of bituminous coal, chiefly developed within the lower Matanuska Valley. These beds represent a period of fresh-water sedimentation of upper Eocene age, as shown by the fossil plants contained in them. The rocks are well indurated, and, as first noted by Mendenhall, resemble the Paleozoic coal measures of the Appalachian region. Since they were laid down they have been subjected to sharp folding and now stand in vertical attitude in portions of the area. They are affected by a great number of faults of small throw.

The Kenai rocks of the Matanuska Valley differ markedly from those of the type section of the Kenai as exposed at Kachemak Bay, on Cook Inlet. In this latter locality the sandstones are soft and incoherent, the shales are plastic when wet, and the lignite seams form the resistant members. The beds lie at low angles in undisturbed attitudes. With this lesser degree of alteration and folding may apparently be correlated the fact that the coal of Kachemak Bay is of much lower grade than that of the Matanuska Valley.

The inferior character of the Jurassic coal of the Matanuska region compared to that of some of the Tertiary coal of the same province has already been mentioned. The Tertiary rocks have, as a general rule, been more highly folded than the strata of older age to the north, and it is a fact of some interest that certain *Aucella*-bearing sandstones of upper Jurassic age show a lesser degree of consolidation than the sandstones of the Tertiary.

7. *Pleistocene stream and glacial gravels.*—The larger part of this formation is made up of the glacial and fluvio-glacial gravels which underlie the Copper River plateau to a depth of several hundred feet, as exposed in the gorge of upper Matanuska River. They are probably not of economic importance. These gravels should not be confused with the gravels formed in the present streams.

8. *Dikes.*—In addition to the bedded volcanics of Jurassic and Tertiary ages, dikes and sills of diabase are widely prevalent. They reach their greatest development in the region east of Chickaloon Creek and along Anthracite Ridge between Boulder and Hicks creeks, where they attain a thickness as great as 500 feet. Their texture varies from finely granular to coarse ophitic. They cut all the rocks of the area, and thick sills of diabase are included between strata of Kenai age. It is probable that these sills are the subterranean accompaniments of the great outpouring of Tertiary basalts.

The Tertiary lavas have not been indicated on the map on account of the unnecessary detail which they would introduce. They are widely distributed and cap the older formations, forming many of the peaks and summits of the region.

STRUCTURE.

As Martin has indicated, the general structure of the Tertiary coal-bearing rocks trends northeast and southwest, parallel with the trend of the valley. Open folding parallel with this direction and accompanied by faulting with northeast trend is characteristic. Minor folds with axes in varying directions are present, that at the coal openings on Chickaloon Creek being an example. Here the axis of an anticline and an adjacent syncline trends southeast and northwest.

Along the northern boundary of the field, between Little Susitna River and Eska Creek, the sandstone beds forming the ridge dip

steeply to the south. There is physiographic evidence of faulting at the base of this ridge, as well as of block faulting within the lower hills of the valley. A fault occurs near the base of the mountains on Eska Creek. Another may be observed on Chickaloon Creek, near the northern edge of the valley. The trend of these faults and their occurrence in rough linear arrangement along the northern boundary suggest structural rather than erosive origin of the Matanuska Valley.

East of Hicks Creek the older rocks of Jurassic age do not present the same structural features. The sediments of the upper Jurassic trend northwestward, whereas those of the lower middle Jurassic strike in a northeasterly direction. Block faulting and open folding are present in both of these formations also. More data must be collected before the nature of the relations of the older rocks to those of Tertiary age can be clearly understood.

ECONOMIC GEOLOGY.

COAL.

AREAL DISTRIBUTION.

So far as known, the Tertiary coal-bearing rocks occurring in the Matanuska basin cover an area of about 380 square miles. Coal-bearing rocks of Mesozoic age developed in the upper Matanuska basin cover approximately 500 square miles. The areal extent of these divisions is shown on the map (fig. 2, p. 106) and the character of the beds has been described above. The mapping of the coal-bearing rocks must in no sense be taken to mean that areas so mapped are underlain by workable coal seams. So far as known, the actual area underlain by coal from Tsadaka Creek to Hicks Creek, inclusive, approximates 70 square miles. Localities where coal of commercial importance has been observed will be described.

There are three kinds of coal within the region—anthracite coal, confined to a small area in the Mesozoic rocks; high-grade bituminous coals, occurring in the eastern portion of the Tertiary field; and high-grade lignite, found in the western division of the Tertiary field and in certain localities in the upper Matanuska Valley associated with Mesozoic rocks.

Coal outcrops have been observed on Tsadaka, Eska, Kings and its tributaries, Chickaloon, and Coal creeks; on the small streams heading in the Talkeetna Mountains between Boulder and Hicks creeks; on Hicks and Billy creeks; and on the banks of Matanuska River about 3 miles above the mouth of Chickaloon Creek. They have also been reported from Boulder and Caribou creeks, from a creek on the south side of the Matanuska 9 miles above Coal Creek, and from Little Susitna River.

Last season's work extended the known area of Tertiary coal-bearing rocks approximately 18 miles up Chickaloon Creek, though no outcrops of coal were observed. The discovery of an area of Mesozoic rocks in the upper Matanuska Valley also extends the field in that direction, as indicated on the map, though all the outcrops of coal north of Anthracite Ridge, which lies between Hicks and Boulder creeks, are of a lignitic nature.

The following paragraphs contain a brief description of the several localities where coal has been observed:

ANTHRACITE.

Anthracite occurs along the flanks of the Talkeetna Mountains, between Boulder and Hicks creeks. It has the ordinary physical characteristics of most good coal of this kind, being heavy, firm, hard, and not much fractured. It has a high luster. The seams are not much broken by small partings of shale and bone. Two sections were measured by Martin. One, on the south side of Purinton Creek

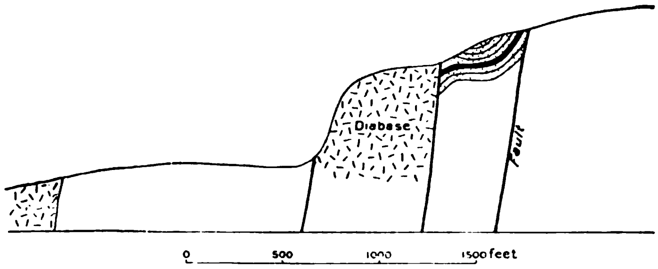

FIG. 3.—Cross section showing relation of anthracite to intrusive diabase near Purinton Creek.

at an elevation of 3,410 feet, showed 38 feet of clean coal with both roof and floor concealed. At this point the rocks strike N. 40° E. (magnetic) and dip 10° NW. into the mountain. The rocks in the vicinity are chiefly graywacke and sandstone and show considerable variation of strike and dip. A mass of diabase occupying the axis of an anticline which is in other places broken by a fault occurs a short distance below the coal.

Martin [a] states that "the anthracite is probably restricted to a zone along the face of and in the mountains which is cut off from the valley plateau by a fault following the base of the mountains."

About a mile northeast of this locality, at an elevation of 3,460 feet, the second section measured by Martin showed four seams of coal aggregating a thickness of 21 feet. The strike is N. 60° E. and the dip 55° SE.

Two sections measured during the last season, farther east on the ridge, showed in one place 7 feet of coal more or less mixed with shale,

[a] Op. cit., p. 18.

and in the other an aggregate thickness of 11 feet 6 inches of coal, though no seam exceeded 2 feet 6 inches in thickness. At the first locality the strike is N. 70° W. (magnetic) and the dip 40° S.; at the second the strike is N. 80° E. (magnetic) and the dip 34° S.

In a small creek west of Purinton Creek is exposed a synclinal of coal, 3 feet thick, cut off by a heavy diabase dike, as shown in fig. 3.

It is believed that the anthracite of this region covers only a small area. The rocks are closely folded, and the seams are cut off by thick diabase dikes. Though it is not certain that the intrusion of diabase dikes is the cause of the anthracitic nature of the coal in this vicinity, its presence at least suggests the possibility of such an influence. At other localities in areas of Tertiary rocks diabase dikes are found in immediate contact with bituminous coals, which in some places have been altered to a dense coke. None of these latter coals can be classed as anthracite. However, in the vicinity of the anthracite, diabase is present in greater mass than elsewhere observed near the coal, and it is reasonable to suppose that the heat derived from its presence was at least a supplemental agency in causing the formation of anthracite.

BITUMINOUS.

The bituminous coal field of the lower Matanuska Valley may be divided into two districts—the eastern and western. Under the first may be included the coals of Kings and Chickaloon creeks and those on both sides of the Matanuska in the vicinity of Chickaloon Creek; under the second, the coals of Tsadaka and Eska creeks.

EASTERN DISTRICT.

Martin[a] states in regard to the coal of the eastern district:

> The coal in this area all possesses about the same physical characteristics, and, as will be seen by the analyses, the variation in chemical composition is not great and supports this grouping. It has the ordinary properties of most bituminous coal. It is soft and fragile, but often without any well-defined planes of fracture. It burns with a short flame and a small amount of smoke and possesses distinct caking properties. The seams generally contain a large amount of impurities, both in the form of thick partings of shale and as thin bands of shale and bone. Many of these can not be separated in mining. The coal is soft and friable, and much of it will not stand severe handling without crushing. Pyrite is present both as balls and as scales, but not abundant. The friable character of the coal is not a great detriment when it is considered that much of it will probably have to be crushed and washed (especially for coke making) and that the coal when used for steam or heating will cake as soon as put in the furnace, so that there will consequently be little or no loss through the grates.

On the south bank of Matanuska River, 3 miles above the mouth of Chickaloon Creek, three coal seams have been found. The upper seam, 7 feet thick, is separated from the middle seam by 43 feet of shale and a 6-inch stringer of coal. The lowest seam, 5 feet 8 inches thick, is separated from the middle seam by 13 feet of shale, which

[a] Op. cit., p. 19.

includes an 8-inch and a 6-inch seam of coal. The strike at this locality is N. 36° E. (magnetic) and the dip 44° SE.

On Coal Creek, which enters the Matanuska from the south a short distance above Chickaloon Creek, coal occurs at three localities. At the first, at an elevation of 1,010 feet, three benches of coal, 2 feet, 1 foot 5 inches, and 1 foot thick, are separated by sandstone and shale partings. The strike is N. 64° E. and the dip 70° SE. About 500 feet farther upstream coal seams are seen intruded by sills of igneous rock. Here 5 feet 5 inches of coke occurs under an intrusive sill 12 feet thick, mixed with coke and overlying a second intrusive sheet 14 feet thick. Ten feet below this second sheet 6 feet 3 inches of coal, followed by two small seams 6 inches and 9 inches thick, may be seen. The strike and dip are as above. Half a mile above the first coal described a 6-foot seam may be observed striking N. 60° E. and dipping 55° NW. It may be seen from this northwestward dip that a possible syncline exists between this upper coal and the two localities

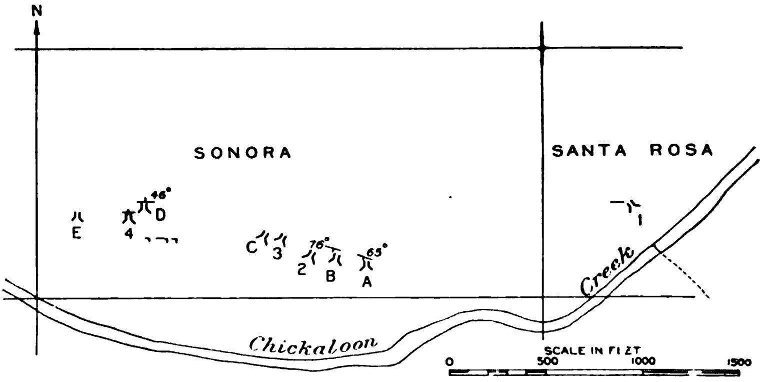

FIG. 4.—Sketch showing location of Chickaloon tunnels.

previously described. As the mouth of Coal Creek is approached a flattening in the dip may be observed, and on crossing the Matanuska and ascending Chickaloon Creek a quarter of a mile an anticline with axis striking N. 50° E. is found crossing the creek. The limbs of this anticline dip at an angle of 30°. Coal was observed in it, but measurements could not be made.

At a point on Chickaloon Creek 1¾ miles above its mouth, but only half a mile in a straight line from the Matanuska, the most important coal openings of this region have been made. Nine tunnels have been driven, crosscutting a number of coal seams cropping in a steep bluff on the north bank of Chickaloon Creek. (See fig. 4.)

Only the thickness of the coal measured in the several tunnels will be given here, the more complete section being reserved for a detailed report. The change of direction of dip which is evident between tunnel D and those farther east (C, 3, 2, B, and A) may possibly be

explained by the presence of an anticlinal axis passing westward from the anticlinal fold at tunnel No. 1, or possibly by irregularities in beds representing the south side of such an anticline. It has been found difficult to correlate the several beds within these tunnels, because of striking irregularities in their thickness. In tunnel A three seams were seen. The first at the face measured 16 feet 7 inches, in which is included a 9-inch layer of bone and coal 1 foot 2 inches from the bottom. The second seam is small, containing but two narrow 8-inch layers separated by 5 inches of bone and shale. The third seam is 3 feet thick and occurs 77 feet from the mouth of the tunnel.

In tunnel B as many as six distinct seams were measured. Several of these, however, contain intervals of shale. Near the face of the tunnel a 2-foot 1-inch seam occurs in which is included 4 inches of bone. On passing outward a thickness of 5 feet 9 inches of sandstone brings the section to a 17-foot 3-inch seam. As in tunnel A, a 1-foot interval of bone is seen near its floor. This seam is undoubtedly to be correlated with the thick seam of tunnel A. Toward the mouth of the tunnel the following coal occurs: A 6-foot seam of bony coal in which is included a foot of sandstone; a 2-foot 4-inch seam of coal; a 7-foot 6-inch seam, at the top of which is 1 foot of bone. Two feet below this seam is 3 feet 7 inches of coal, 7 inches of which is bone.

In tunnel No. 2 a thick bony seam that occurs in B was measured, but shows 12 feet 11 inches. It is in this tunnel very bony and includes 1 foot 6 inches of shale near its middle. A drift has been run from B to No. 2, so that there is no doubt of the correlation. A second seam, separated from this one by 18 feet of shale, measures 4 feet, 7 inches of which is bony.

Tunnel No. 3 reveals the thick seam at the face. Its total width could not be seen, but 7 feet 10 inches may be measured, including a 2-foot interval of shale which probably corresponds to the 1 foot 6 inches of shale in the same seam in tunnel No. 2. The second seam of tunnel No. 2 has in No. 3, 2 feet 5 inches of very bony coal in its center. Its total width is 16 feet 2 inches. About 20 feet from the mouth of tunnel No. 3 a third seam measures 4 feet 1 inch. Small streaks of bone occur in it.

In tunnel C but one small seam was measured. It was 4 feet thick, 2 feet of which was coal with shale.

In tunnel D two seams of crushed coal, each 2 feet 6 inches thick and separated by 49 feet of sandstones and shale, were seen.

In tunnel E 10 feet 11 inches of coal containing several 6-inch streaks of bone and 2 feet of crushed shale mixed with coal was seen.

At the face of tunnel No. 4 a thickness of 5 feet of crushed coal was exposed

Considerable variation in the thickness and in some places unexpected interruptions of the seams are disclosed in these tunnels. Whether faulting or pinching out of the coal be the explanation, further work must show. The rocks in the near vicinity are closely folded, and faulting, with the added difficulties of mining which it incurs, should be expected.

On Kings Creek, 7½ miles above its junction with the Matanuska, coal seams are cut by the creek, on both sides of which they were measured. A seam of impure coal 6 feet 6 inches thick, overlain by 5 feet 5 inches of dense impure coke, is seen on the east bank. On the west bank coal occupying a stratigraphic position approximately 6 feet lower than this seam measures 10 feet in thickness. In it are several streaks of bone 4 to 8 inches in width. The strike is N. 42° W. (magnetic) and the dip 42° NE. A short distance upstream from the exposure on the east side the sandstone beds are considerably disturbed. Folding or faulting, or possibly both, has occurred.

On Young Creek, a tributary of Kings Creek from the west, 1 foot 1 inch of coal was seen by Martin, and below it a 6-inch seam was found. Workable seams are reported on this creek. The strike of the beds at this locality is N. 15° E. (magnetic) and the dip 20° NW.

WESTERN DISTRICT.

The coal of what has been termed the western district—i. e., that occurring on Tsadaka and Eska creeks—is a bituminous coal of low grade. Its physical properties are much the same as those of the coals farther east. Most of it is bright and hard, though dull shaly bands are numerous. On Eska Creek, at an elevation of 875 feet, 7 feet 8 inches of coal in which are included four shale streaks and some bony coal was measured. The strike is N. 30° E. (magnetic) and the dip 44° NW.

About 300 feet farther upstream 7 feet of coal is exposed, 15 inches of it being made up by the shale streaks. This coal dips to the northwest.

About 600 feet above the section first cited 2 feet 6 inches of clean coal and 1 foot or more of dirty coal may be seen dipping 32° SE.

On the west bank of the creek, at an elevation of 1,030 feet, a steep bluff made by stream erosion reveals a number of seams of coal. A marked fault cuts this bluff. The strata above it, in which the coal was measured, strike N. 40° W. (magnetic) and dip 40° SW. Below the fault the beds strike northeastward and dip to the southeast. At the top of this section are three seams, none of which exceeds 2 feet 3 inches in thickness. They are separated by small intervals of shale. About 12 feet lower in the bluff follow coal and shale bands aggregating 12 feet in thickness, but containing no solid coal thicker than 2 feet 1 inch. Two 1-inch seams separated by 2 feet of shale occur 12 feet lower.

On Moose Creek about 11 feet of good coal is exposed 100 yards below the upper cabin. The seam strikes N. 80° E. and dips 45° N. A strike fault dipping 80° S. can be seen crossing the bed, with a throw of about 5 feet. An eighth of a mile downstream from this exposure a sharp syncline crosses the creek, with axis striking about S. 70° E. and dipping steeply to the west.

A short distance farther downstream coal beds are exposed striking N. 70° E. and dipping 60° N. This direction does not accord exactly with the synclinal axis. In these beds the thickest seam measured 3 feet 6 inches of clean coal. Higher in the section were found two seams, each 1 foot 7 inches thick, but consisting partly of bone.

On passing up Moose Creek and following the ridge on its southern side sandstones may be observed dipping to the southeast, which is the opposite direction from that of the beds just described. Still farther east conglomerate beds dip to the southwest. There is undoubtedly block faulting within this area, and should the coal beds be followed eastward it would probably be encountered.

It will be noted that at nearly all the localities above described faulting or folding is present. Such a condition will surely place the cost of mining higher than it would be if the beds were less disturbed.

LIGNITIC COALS.

At various points in the region north of Matanuska River thin seams of coal were found in rocks of Jurassic age. None exceed 3 feet in thickness. In the vicinity of Billy and upper Caribou creeks the highly shattered condition of the strata is unfavorable to the presence of workable deposits of coal.

On Billy Creek is exposed an interesting section showing very clearly the complex history through which the coal has gone since its formation. The coal-bearing strata have been folded into a closely appressed anticline. Subsequently they have been cut by basaltic dikes, coking the coal at the contacts. The dikes have been faulted, with a displacement of 5 feet, and the coal has been crushed and sheared, and finally small stringers of quartz, 2 to 3 inches thick, have been formed, accompanied by veinlets of calcite in the coal.

GOLD.

DISTRIBUTION OF GOLD-BEARING ROCKS.

Gold-bearing rocks are found over considerable areas in the region adjacent to Cook Inlet. A graywacke and slate series cut by small quartz stringers occupies the eastern part of Kenai Peninsula, extends across Turnagain Arm, and may be seen in the valley of Knik River still farther north. The search for placer gold in rocks of this type is warranted and discoveries of commercial quantities may be expected where they appear.

North of Matanuska River, on the southern margin of a granite mass, occurs a band of highly crystalline mica schist. It is closely folded and infiltrated with fine quartz stringers, and streams cutting it yield gold placers. It is noteworthy that the igneous rocks, granitic and volcanic, to which this schist gives way on the north and east have so far proved barren of workable placers.

To the northwest, near the mouth of Talkeetna River, a slate-schist series, folded, intruded by granite, and containing abundant quartz stringers, represents the gold-bearing rocks. Eldridge[a] reports the occurrence of similar rocks north of the Susitna-Tanana divide. Some gold has been found in the past on streams heading within this formation. The gold-bearing gravels of the new Yentna district are reported to have a slate bed rock, indicating the presence of the same formation.

Though there is yet some question as to the relative ages of these several series of rocks, there is little doubt that their economic importance is due to the mineralization accompanying local infiltration of quartz stringers. In the subsequent wearing away of the rocks the gold content therein has been concentrated in the form of placers.

Though placers have not been found within the areas of older volcanic rocks, some mineralization has occurred. West of Hicks Creek a large cropping of gossan was found. This gossan is due to the oxidation of finely divided pyrite disseminated through a quartz porphyry. A sample selected for assay showed a trace of gold and no silver.

The whole southern flank of Sheep Mountain, at the head of Matanuska River, is colored a strong red from the oxidation of pyrite in the greenstones. At some points the sulphuric acid formed during the oxidation of the pyrite has bleached the greenstones entirely white, and this bright color, contrasting vividly with the red, produces a marked scenic effect. Certain streams emerging from the range are so highly charged with iron salts as to coat their gravels red with oxide. The mineralization of the greenstones, which are here roughly schistose, is extensive but diffuse. An assay showed the presence of a trace of gold, but no silver.

DESCRIPTION OF LOCALITIES.

WILLOW CREEK.

Placer gold is being mined in commercial quantities only at one locality within the area covered during the season—on Grubstake Gulch, a southern tributary of Willow Creek, which enters Susitna River about 30 miles above its mouth. Willow Creek proper was staked by M. J. Morris and L. Herndon in 1898, and it is reported that

[a] Eldridge, G. H., A reconnaissance in the Susitna basin and adjacent territory, Alaska: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 15-16.

they extracted about $4,000. In 1899 A. Gilbert staked Grubstake Gulch and in 1900 sold his interest to O. G. Herning, who manages the property for the Klondike Boston Mining Company, of Boston, Mass.

The valleys of Willow Creek and of the small tributary gulches show clearly the results of ice action, the side streams occupying hanging valleys, with steep gradients or falls where the smaller streams join the main watercourses. Grubstake Gulch is an example of such conditions. Near its mouth a rim of bed rock crosses the stream and is cut through by the present stream, which falls precipitously about 150 feet in a very short distance and enters Willow Creek at a low gradient. An excellent dump for hydraulicking is thus afforded. The bed rock is a mica schist, penetrated by minute veinlets and augen of quartz. The schistosity at this point is S. 60° W., with a steep dip (40°) to the north. The fact that the direction of the schistosity is across the stream with the dip downstream is especially favorable for the collection of any gold that might be concentrated from the rocks in the process of erosion which the valley has undergone.

In the last three years, during which time hydraulic methods have been in use, 900 feet of the creek has been worked out. Pay averages 200 feet in width, with a depth of 2½ to 3 feet. The gold is coarse and rough and at the mint assays $16.58. Very little black sand is found. The greater part of the gold occurs close to or in crevices of the bed rock, but it is not deemed necessary to clean up by hand, the hydraulic giant being relied on entirely to sweep all gold into the boxes. The wash, which is practically all confined to the gulch bed, there being no well-defined bench, is coarse, ill sorted, and not greatly waterworn. Many large bowlders make it necessary to employ at least two men in breaking up and removing oversize, which adds materially to the cost of extraction. Three Hendy giants are installed on the property, two No. 2 and one No. 1. Only one is used at a time, however. Seven hundred inches of water at a pressure of 180 feet is brought three-fourths of a mile down the gulch. A 24-inch pipe at the intake dam is reduced to 9 inches at the giant, to which is fitted a 3-inch nozzle. The 900 feet of sluice boxes used are built entirely of whipsawed lumber. The bottom boards are 1½ inches thick and the side boards 1 inch thick; the frames are 3-inch square timbers. The flume is 27 inches wide and 30 inches deep, inside measurements. Block riffles are used. A grade of 5¼ inches to 12½ feet is maintained. The gravel is piped downstream into the boxes. Very little gold is caught below the fourth box, the greater part being retained in the second. Mercury is placed in the third, fourth, and fifth boxes.

The origin of the gold may be with certainty accorded to the quartz stringers abundant in the mica schists. The coarseness and roughness of the grains suggest a near source of supply. It is very probable that the discovery of placer gold in commercial quantities in

this region will be in the areas where mica schist is the dominant formation or where streams have cut rocks of that type. The fact that placer gold has not been found in paying quantities where streams have headed in granitic or other crystalline rocks bears out this statement.

Recent prospecting has developed the fact that a well-defined bench occurring about 75 feet above the bed of Willow Creek carries gold in commercial quantities. It is planned to install during the coming winter a hydraulic plant for their exploitation near the mouth of Wet Gulch, 2 miles below Grubstake Gulch, on the south side. The location, with excellent facilities for dump and a catchment area at least as large as that of Grubstake Gulch supplying water under sufficient pressure, suggests a commercial proposition well worth investigation. The possession of the creek claims as dumping ground will be necessary. Such bench claims lend themselves particularly to exploitation by hydraulic methods and may be worked at far lower cost than gravels situated at the level of present stream drainage.

NELCHINA RIVER.

Two prospectors from Copper Center were met in the headwater country of Nelchina and Tyone rivers. Gold was reported present in all the stream gravels, but in very small quantities. The gold obtained on the Tyone is almost exclusively in the form of small round plates, worth about a cent a piece. Occasionally small shotty nuggets are found, not exceeding 5 or 10 cents in value.

Panning of the hard conglomerate interstratified with Jurassic shales and sandstones failed to yield colors. Yet, in view of the unaltered and unmineralized character of the prevailing sandstones and shales and the comparative coarseness of the gold, it is nevertheless probable that the meager gold content of the present stream channels has been derived by a concentration of the ancient conglomerates.

KNIK RIVER.

It is reported that prospectors discovered gold on Metal Creek, a tributary of Knik River, $7 or $8 a day to the shovel being claimed.

YENTNA DISTRICT.

The following data are compiled from various sources: The placer gold diggings of the New Yentna district are located approximately 75 miles northwest of the mouth of Susitna River where it enters Cook Inlet. They occupy in the main the headwaters of Kahiltna River, a northern tributary of the Yentna, 25 miles above the latter's confluence with the Susitna. The Yentna heads in the Alaska Range and enters the Susitna 20 miles above its mouth.

Except the diggings of Lake Creek, a tributary to Yentna River from the north about 10 miles above the Kahiltna, the workable ground may all be classed as shallow, varying in depth from bare bed rock to 5 feet. On Lake Creek the surface gravels only are washed, bed rock never having been reached. It is reported that the pay is from 2 to 5 feet deep and varies in width from 10 to 30 feet.

The gold, with which much black sand occurs, is fine, and at Susitna station (at the junction of Yentna and Susitna rivers) brings $15.75.

About 35 miles above its mouth Kahiltna River forks, its eastern branch being called Peters Creek. Near the head of the latter are Willow and Poorman creeks, both fair producers during the last season. Poorman Creek is tributary to Willow Creek, which in turn enters Cottonwood Creek, a tributary of Peters Creek, between the upper and lower canyons.

The remaining creeks of first importance are all western tributaries of Cache Creek, which enters the western branch of Kahiltna River from the northeast about 20 miles above the mouth of Peters Creek. They are, in order, proceeding upstream, Dollar, Falls and its tributary Treasure, Thunder, and Nugget creeks. They are all located above timber and are characterized by shallow ground and coarse gold. An ounce to the shovel was generally obtained. The bed rock on all these creeks is reported to be slate.

During the open season the steamer *Caswell* and several gasoline launches run from Tyonek, on Cook Inlet, to Lake Creek. A trail to the diggings from Youngstown, on the Yentna, 40 miles above Lake Creek, is also used.

It is probable that $35,000 is very close to the actual production of the district.

SUNRISE DISTRICT.

The following notes on the status of mining in the Sunrise district were gathered at the end of the field season while en route to Seward. The greater part of the mining done last season was confined to Resurrection Creek and its tributaries, Crow Creek, Sixmile Creek, East Fork, Canyon Creek, and Mills Creek. A small amount of work was probably done on a number of other streams, but the quantity of gold produced could not have been great.

Mining has been in progress for a number of years[a] on all the above-named creeks. The richer and more easily accessible portion of the gold content has been removed. Present mining is confined largely to the working of high benches, which, though containing less gold, lend themselves by their position to more economical methods of mining than can be pursued in the creek bottoms. The utilization of

[a] Moffit, F. H., Mineral resources of Kenai Peninsula, Alaska: Bull. U. S. Geol. Survey No. 277, 1906, pp. 33-43.

water under pressure brought by ditches or pipe lines to hydraulic giants is the method most generally employed.

Little mining was done on Resurrection Creek during the season of 1906. A dredge installed in 1905 did not prove a success. The shallowness of the ground and the presence of bowlders of such size as to effectually prevent successful operation appear to have led to this result.

A hydraulic plant on Rainbow Creek, which enters Turnagain Arm on the north opposite Resurrection Creek, was not working during the past season.

Developments on a large scale were made on Crow Creek, a northwest tributary of Glacier Creek, which enters Turnagain Arm on its northern shore 8½ miles east of the town of Sunrise. The Crow Creek Consolidated Mining Company began operations June 6, a large hydraulic plant having been installed under exceptional difficulties at a point a short distance above the junction of Crow and Glacier creeks.

The deposit being mined, aside from its economic value, is of considerable interest in a study of the development of the adjacent region. The following points are to be noted: First, a rock gorge of considerable depth cut in bed rock; second, the gorge, as well as a considerable extent of territory on each side, filled or overlain by a notable thickness of water-laid sands, silts, and gravels; third, recent stream action, superimposed upon these gravels, cutting through them, and forming the present gorge, now far below the older one.

It seems reasonable that the cutting of the first gorge may be referred to preglacial stream action. The glacial striæ and rounded surfaces on the exposed bed rock below the pit at the old level of erosion are excellent evidence of the former presence of the ice. The encroachment of the ice down the main valley of Glacier Creek and the accompanying occupancy of Crow Creek by a glacier would account for a cessation of the cutting of the old gorge. It is assumed that either the mass of the trunk glacier acted as a barrier while the side gulch was already clear of ice, or lateral morainal deposits from the trunk glacier were sufficient to dam the valley of Crow Creek, offering an opportunity for the filling of the old valley of that stream by a process of intermittent flood and low-water deposition. The character of the sediments exposed in the upper pit would strongly suggest such an origin for them. Moreover, the cemented condition of the old gravels lying immediately next the old bed-rock surface is evidence of a quiescent stage in their history such as might occur were they buried in a lake deposit. The erosion of a new channel through this thickness of gravels, sands, and silts, with the consequent formation of the present gorge, was the final step in the history of this creek.

The following is a description of the lant: Water is supplied by a

ditch 5,700 feet in length, 6 feet wide at the top and 4 feet at the bottom, and 4 feet deep. To the ditch is added a pipe line 3,000 feet long, reduced from 24 inches in diameter at the ditch intake to 15 inches at the giant. An abundance of water was obtained until September 8, when the supply fell below 2,000 miner's inches, a quantity insufficient to work to the best advantage a plant of this size. Operations may begin as early as May 15. Two No. 7 giants, with 15-inch intakes, were installed. The pressure varied between 280 and 330 feet, depending on the position in the pit.

Up to September 21 200,000 yards had been moved. The gold-saving apparatus consisted of a string of sluice boxes 200 feet in length occupying a bed-rock cut at a grade of 8 inches in 12 feet. Ample dump space is afforded by a rather peculiar topographic feature. The pay gravel occupies an old stream channel cut in a steep gorge of bed rock. Cutting through this old bed is the present more recent creek course, which has lowered its level many feet below the old channel. As a result, there is excellent opportunity for the disposal of tailings. The sluice boxes are 5 feet 3 inches wide inside the lining boards. Twelve-inch cube hemlock block riffles are used. Their life is about three months. It is found that hemlock from this region is tougher and wears longer than the fir of the western United States. Attached to the end of the tail sluice is an undercurrent. It is divided into three tables, each 6 by 30 feet, fitted with 6 by 2 by 2 inch block riffles nailed to a cross strip. The first 4 feet of each table, however, is fitted with rock riffles, which, though they offer a slight disadvantage in the difficulty of setting up and removal, can be commended because of their durability and efficiency. The presence of numerous large bowlders required the installation of a tram from the pit to the tailings pile. Bowlders less than a foot in diameter which the hydraulic giant is unable to move are trammed out. Those greater than a foot in diameter are blasted and then treated in the same manner. It was found that in the lower heavy ground a duty of only 1 cubic yard per miner's inch was obtained, whereas in the top ground, where the wash is regular and bowlders not abundant, a duty of 3 cubic yards per inch could be expected. The gold is for the most part fine and assays $14.90 per ounce.

A second pit worked a short distance below the one just described differs in the character of its bed rock. An area about 350 feet long by 100 feet wide was piped down through an average depth of about 10 feet, where a clay and cement-gravel bed rock retained the pay. Hand cleaning was necessary, though the taking up of the bed rock was not deemed profitable.

About 2 miles above the plant just described, at the mouth of Milk Gulch, a small tributary of Crow Creek from the northeast, mining was in progress by hydraulic methods the greater part of the season.

In all, about 50,000 yards of gravel were washed from two pits, with reported satisfactory results. The deposit worked lies in a basin formed by the damming of Crow Creek by a terminal moraine, left after the retreat of the glacier which formerly occupied its valley. A cut through this moraine had been run at considerable expense to tap the bedded deposits lying above it. At the upper pit a giant using 200 inches of water under a pressure of 240 feet had moved 15,000 yards. The flume from this pit was 3 feet 9 inches deep by 50 inches wide and floored with 8-inch square blocks. The posts and sills were 4 by 6 inch timber, and the lining boards were 3 inches thick. The side and bottom boards were made of 1½-inch lumber. A grade of 7 inches in 14 feet was maintained, and the tailings were dumped in Crow Creek. A 5-ton derrick, reported to move 1½ yards a minute, was used in removing rock too large to put through the flume. Thirty inches of water under a pressure of 200 inches was sufficient to run the derrick. In the lower pit 25,000 yards was moved in ten days by two giants equipped with 5-foot nozzles and supplied each with 250 inches of water under a head of 250 feet. Above the upper pit, jutting out from the mountain side on the northeast, may be seen what appears to be a remnant of the valley filling consequent on the damming of Crow Creek by a glacial moraine. It consists of a ridge of ill-sorted angular material, cemented by a fine rock-flour silt, a condition to be expected where deposition was as rapid as would occur near the head of a gulch of extremely steep gradient. It is reported that a drift run into the deposit disclosed prospects of sufficient value to warrant mining by hydraulic methods, and it is planned to begin active work next season.

Mining on Sixmile Creek, which enters Turnagain Arm at the town of Sunrise, was not carried on with any great activity during 1906, but the high benches along its course were worked by individuals with small outfits at several localities. Work in the stream gravels proper amounted to little. At the forks of Canyon Creek an attempt was made to reach bed rock by means of a hydraulic elevator. What success attended the work was not evident at the time of visit, as work had ceased.

Bench claims on Gulch Creek, a tributary of East Fork a short distance above its junction with Sixmile Creek, produced a small amount.

On Canyon Creek the most important work was that by S. W. Wible. About 50,000 cubic yards were moved during the season by hydraulic methods from a bench claim on the east side of the creek. Water, which during the height of the season amounts to 1,000 or 1,500 inches, is brought through a ditch 4 miles in length. The ditch measures 6 feet at the top, 3 feet at the bottom, and is 3 feet deep.

It was built at a cost of about 60 cents per cubic yard. Owing to the usual inadequate water supply during the last third of the season, it is planned to build 12 miles of ditch to Summit Lake at the head of Canyon Creek. This ditch, which is now partially built, is 5 feet wide at the top, 3 feet at the bottom, and 2 feet deep. A contract price of $2.50 per rod has been made, which is 10 cents cheaper than the old ditch. Two giants fitted with 4-inch nozzles are used when an abundant supply of water is available. As the water falls, the size of the nozzle is reduced. A yardage of 1,000 cubic yards per day can be maintained at a reported working cost of 4 cents per yard. This figure is exceptionally low, and probably can not be realized without most careful management. The gold-saving apparatus, which is adapted to the precipitous bluff upon which the bench is mined, is a combination of sluice boxes, grizzles, and undercurrents combined in an ingenious manner. A main sluice of four box lengths, with 11-inch grade and fitted with riffles, is terminated by a steeply inclined grizzly over which large rocks pass to the dump. The grade of the grizzly is 5 feet in 16 feet, and the bars are 4½ inches apart. Fitted beside the main sluice are two undercurrents fed by material passing through grizzly bars 3½ feet long and 2½ inches apart. The undercurrents have a grade of 8 inches to 12 feet, are each 6 feet long by 3 feet wide, and are fitted with slot riffles. The material from the undercurrents passes by a small sluice to meet the material which falls through the large grizzly at the end of the main sluice, and with it runs down a second large sluice at right angles to the first. Undercurrents from the second sluice are arranged in a similar way to those above described. A third turn in the arrangement of the boxes brings the wash, now thoroughly cleaned, back to a point nearly beneath the large grizzly at the end of the first sluice. The arrangement is said to be very satisfactory.

On Mills Creek, a tributary of Canyon Creek from the southeast, a small amount was produced. At one point drifting was carried on with reported success.

On Cooper Creek, a tributary of Kenai River 2 miles below its source, benches carrying gold in commercial quantities are reported.

Though no gold was produced the last season on Lynx Creek, a tributary of East Fork 8 miles above its junction with Sixmile Creek, development work of importance was completed. It is planned to work the gravels near the mouth of this creek by hydraulic methods. To reach bed rock and to avoid the thick deposit of coarse wash at the mouth of the creek, upon which sufficient grade for a dump could not possibly be secured, a 600-foot tunnel has been run through a sharp ridge, reaching a point where the valley of East Fork is lower than the bed-rock floor of Lynx Creek. The tunnel is 6 feet high by 5 feet

wide and cost $10 per running foot. By extending a tailrace across this flat, as débris collects, a practically unlimited dump may be obtained. A flume 3 feet wide and 2 feet high, fitted with block riffles, will be used. Lumber, either whipsawed or brought in, costs about $100 per thousand. It is reported that abundant water to work two No. 1 hydraulic giants under a head of 400 feet can be secured by a 1,000-foot pipe line 8 inches in diameter. The gravel bank, of which the greater part may be piped to the sluice, is 25 feet deep and is reported to run 50 cents to the yard. The gold is coarse, nuggets up to $20 and $60 having been found.

COPPER.

KNIK RIVER.

In August, 1906, prospectors reported the discovery of copper in the high mountains between Knik and Matanuska rivers, but this locality was not visited. The ore is chalcopyrite (sulphide of copper and iron) and is associated with pyrrhotite (magnetic iron pyrites). The ledge is reported to be nearly vertical and has been traced through four claims. No actual development work has been done. The ore body is said to be 3 feet thick, consisting of 18 inches of solid chalcopyrite and 18 inches of quartz irregularly cut by stringers of ore. Graphitic gouge matter occurs near the ledge. From the foregoing description it appears probable that the deposit occupies a mineralized shear zone similar to those found in the Prince William Sound region, both in its manner of occurrence and in the bed rock with which it is associated. The mountains between Knik and Matanuska rivers, though difficult of access, are thought worthy of prospecting.

KASHWITNA RIVER.

During the summer of 1906 assessment work was done on copper claims near the head of the north fork of Kashwitna River, a tributary of the Susitna from the east. Samples of bornite said to occur in a granite were seen. The claims are about 120 miles from Knik and 10 miles from timber.

SUNRISE DISTRICT.

A copper prospect located on the west side of Lynx Creek, a southern tributary of East Fork, near the summit of the divide near its head, is being developed by the Ready Bullion Copper Company, of Boston, Mass. The country rock at this locality is a part of the graywacke-slate series composing the central and northern mass of the Kenai Mountains. The dominant cleavage at this point is N. 10° E., a direction nearly parallel with the ridge in which the copper deposit to be described occurs.

At an elevation approximating 3,000 feet a tunnel has been run 350 feet S. 80° W. into the mountain, a direction nearly at right angles to its trend. A drift from a point near the end of the tunnel was driven 150 feet to the south and 90 feet to the north, along a zone characterized by intense slickensiding or shearing in a nearly vertical direction. A short distance beyond this zone a fault dipping 35° W. was observed. Such a dip would not interfere with the continuation of the ore in depth.

Chalcopyrite ore accompanied by pyrrhotite and pyrite with much quartz has been deposited along the zone of shearing disclosed by the drifts. Irregular masses as thick as 2 feet were observed, but their horizontal linear extension was short, the vein fluctuating between 6 inches and 2 feet in thickness. At the south end of the drift the vein was narrow, and at the north end the face did not disclose ore. It was reported that gulches cutting the mountain north and south of the tunnel showed no signs of copper. Stripping, however, had not been done.

A thousand feet below the entrance of the upper tunnel an adit is being driven to catch the ore in depth. A length of 800 feet has now been completed. A rough estimate shows that with continued vertical dip the shear zone would be reached within a distance of 2,000 feet from the mouth of the adit.

THE NOME REGION.

By Fred H. Moffit.

INTRODUCTION.

The work of the Geological Survey in the Nome region was initiated by Schrader and Brooks during the year following the gold discoveries on Anvil Creek in 1898. Their investigations, although undertaken in the late fall and prosecuted under many difficulties, nevertheless resulted in the first statements regarding the high bench gravels and the probable presence of other gold-bearing beaches back of the present beach, whose wealth had then just been revealed. It is worthy of note that this prediction[a] has since been fully justified.

The investigation thus begun was continued in 1900. A geologic reconnaissance was carried on by Brooks, and a topographic reconnaissance map, including a large part of the southern half of the peninsula was made by Barnard. Geologic work was again undertaken in the region in 1903 by Collier, but formed only a part of his studies for that year. The field work of these three seasons was of a reconnaissance character and had as its prime object a study of the occurrence and distribution of the gold. Detailed study of the region was made possible when a much more accurate map representing an area which includes the beach from Cape Nome to a point 3 miles west of the mouth of Snake River, a distance of 15 miles, and extends from the coast to the Kigluaik or Sawtooth Mountains, slightly more than 35 miles, was completed by Gerdine in 1904. (See fig. 5.) Field work was begun in the following spring (1905) by Frank L. Hess and the writer and carried to completion during the summer of 1906 by Philip S. Smith and the writer. The chief aim in this work was to secure, as far as possible, the facts throwing light on the bed-rock source of the gold now found in the gravels and to investigate the processes governing the present distribution of that gold.

It is a fact well known among mining men that by far the greater number of gold placer deposits are largely worked out in a comparatively small number of years, and that lode deposits, though they often yield much smaller values in return for the capital and labor

[a] Schrader, F. C., and Brooks, A. H., Preliminary report on the Cape Nome gold region; a special publication of the U. S. Geol. Survey, 1900, p. 22.

expended in the same length of time, nevertheless tend toward the permanence and stability of a mining camp. While it is believed that the gravel deposits of the Nome tundra, as well as the stream and bench gravels of the district, are sufficiently great in amount and rich in gold content to insure Nome an important place among gold-producing districts for many years to come, still the discovery of valuable lode deposits can be of no small importance for the interests of the region. The discovery and exploitation of such deposits are not made in most mining communities until the available placer ground is largely taken up or until failure of the valuable content compels capital to seek other investment. It is therefore not to be wondered at that only slight attention has yet been given to lode mining in the Nome region.

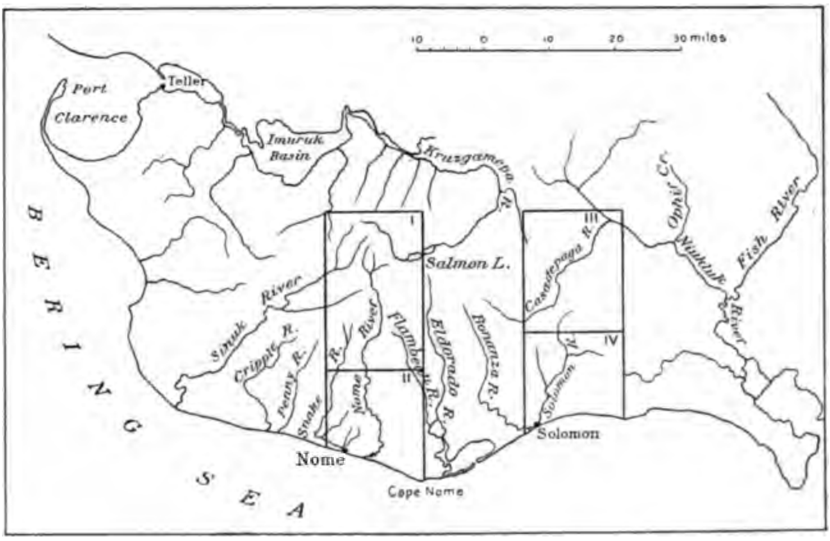

FIG. 5.—Sketch map of southern Seward Peninsula, showing the area covered by detailed topographic maps. I, Grand Central special; II, Nome special; III, Casadepaga quadrangle; IV, Solomon quadrangle.

It is an unfortunate fact that the work of a mining geologist can not be entirely separated from that of the miner, and that the data he requires for the solution of many problems arising in the extension or exploitation of mining properties can be secured only after development has reached a more or less advanced stage, and in many places only after large sums of money have been expended. We have here one reason for the distrust in geologists which mining men not infrequently show. A better realization by both classes of the interdependence of interests, which is already becoming evident, is greatly to be desired and must lead to a greater appreciation of what each owes to the other.

It is the purpose of this paper to give a preliminary statement of the more important facts gathered during 1905 and 1906 bearing on the geology and the source and distribution of placer gold in the portion of Seward Peninsula represented by the two topographic sheets known as the Nome and Grand Central special maps. The paper is not complete, since it goes to press too early to permit a thorough study of the data collected. The final conclusions, together with the two maps mentioned, will be published in a forthcoming bulletin of the Survey.

GENERAL GEOLOGY.

The important features of the bed-rock geology of the region were recognized and correctly interpreted by Brooks and Collier. As stated by them, the rocks are chiefly sedimentary, limestones and schists, but in many places have been intruded in an intricate manner by igneous rocks of several kinds, more especially by greenstones and granite or rocks of a granitic character. Brooks referred the sediments to three periods of time and described them under the names of Kigluaik, Kuzitrin, and Nome series.[a] A brief account of these will be given.

KIGLUAIK SERIES.

The oldest known sedimentaries of this region are exposed in the Kigluaik or Sawtooth Mountains and are well represented in Mount Osborn, a short distance north of the northern limit of the area shown on the Grand Central map. The relative age of the beds is known only by their stratigraphic position, for no fossil remains have yet been found in any of the rocks to be described.

They comprise biotite and graphitic schists and limestones, together with gneisses and granite or related intrusives. In Mount Osborn the schist and limestone beds lie in a nearly horizontal position, but on the southern side of the Kigluaik Range they dip rather gently to the south and beneath the younger sedimentaries. This succession of beds was given the name of Kigluaik series.

KUZITRIN SERIES.

A highly irregular series of beds consisting of siliceous graphitic schists occurring along the south flank and east end of the Kigluaik Range was called by Brooks the Kuzitrin series. It has a regular southerly dip and is not found south of the Salmon Lake valley, but is possibly represented by beds occurring on Charley Creek south of Sinuk River. No conclusive evidence was found within the Grand Central area, however, showing that these black schists should be

[a] See p. 83 (footnote *b*) in regard to use of the term "series."

separated from the underlying Kigluaik series, and in fact exactly similar beds are found interstratified with the biotite schists of that series. A doubt therefore arises as to whether these two should be separated.

NOME SERIES.

South of the Salmon Lake and Sinuk River valleys and extending to the coast of Bering Sea is a region of schist and limestone intruded by greenstone, and in the vicinity of Cape Nome by granite, to all of which the name Nome series was given. In general the strata dip to the north in the portion of the region south of the latitude of Mount Distin and to the south in the portion north of that latitude, thus forming a broad synclinal trough on whose axis Mount Distin is situated. The rocks forming this trough are chiefly schists, with limestone in lesser amount. The greenstones cut both of these in the form of sills and dikes. All have been highly metamorphosed. The limestones, which are found most abundantly in the upper part of the Nome series, have been entirely recrystallized and any organic remains they may have contained are now seemingly obliterated. The original argillaceous sediments, more highly developed in the lower portion of the series, and the greenstones intruded in them are also recrystallized and possess a well-developed schistose structure. The schists may be described freely as micaceous, feldspathic, or graphitic in character according as the minerals mica, feldspar, or graphite are prominent. The micaceous schists, in places highly siliceous, are usually green or silvery gray in color; the feldspathic schist is green, though this color is partly hidden by the development of numerous small feldspar crystals; the graphitic schists are black, becoming gray as the amount of carbonaceous matter decreases and quartz becomes more evident. The feldspathic schists are in many places conspicuous by reason of the abundance of small albite crystals, which are especially noticeable on the weathered surface. They are derived in part from original sediments, but probably in the main from intruded greenstones.

Greenstones are more common as sills than as dikes and are usually highly altered. In general their conspicuous minerals are chlorite and albite, but in some localities they are filled with red garnets. Like the feldspathic schists, into which they grade locally, they are more abundant on the east side of Nome River than on the west and are perhaps most highly developed in the area between Osborn Creek and Nome River.

Only one notable area of granite is found within the Nome series in the region under consideration. It is seen in the two ridges running northward and northwestward from Cape Nome. This granite,

however, does not appear to extend north or west of Hastings Creek, and the entire area occupied by it within the boundaries of the district mapped on the Nome sheet is about 6 square miles. East of the boundary the granite area is probably slightly larger.

STRUCTURE.

It has been stated that the Nome series forms a broad synclinal trough, with an approximately east-west axis, extending from the coast of Bering Sea to the Kigluaik Mountains. There is, however, abundant evidence of an earlier deformation, due to forces acting almost at right angles to those which gave rise to the broad east-west folds and producing other folds much more intense in character and with axes running from north to south or from north-northwest to south-southeast. Yet, in spite of these deformations, it was found that the bedding of the sediments and the cleavage or schistosity are nearly everywhere the same, although exceptions are known.

The Nome series has been deformed under conditions of comparatively light load, as a result of which the strata are much broken, locally with more or less displacement. In places the limestones especially appear to have been crushed, much as a marble block is sometimes crushed under a heavy weight, but on a far greater scale. Faulting of lesser degree is exceedingly common, but direct evidence of large displacements is hard to secure. This is due to the difficulty of finding any reference beds and the well-nigh hopeless task of correlating strata in different or even in neighboring parts of the field. Evidence of faulting is most readily obtained in localities where limestones are present. It is rarely the case that one can actually place hands on the contact of faulted beds, and the displacement is usually indicated by an offsetting of outcrops or the abrupt termination of beds along their strike.

VEINS.

Deformation and rupture of the series has given opportunity for the circulation of mineral-bearing solutions and the deposition of veins of quartz and calcite. Quartz occurs principally as lenses and stringers in the schist, but also as well-defined veins cutting the schist. Veins of white quartz of considerable thickness—10, 12, or even 20 feet—occur, but in no observed case do they show as great mineralization as some of the smaller veins. In several localities prospect holes or short tunnels driven in the large quartz masses show them to be much broken and faulted, and, while the weathered surface is milky white, joint planes and cracks are stained with iron oxide.

Small quartz veins, though less conspicuous, are far more numerous, and, as noted, are here and there well mineralized. They appear as small lenses, either lying in the cleavage or crossing it, as filling along

joint planes, and as narrow veins of fairly regular thickness but small longitudinal extent—that is, much flattened lenses. A broken surface of such a vein may show sulphides, generally pyrite, or more commonly a cavernous interior filled with iron oxide derived from the alteration of pyrite. Some of these veins are known from numerous assays to carry gold in small quantity.

Calcite veins are almost restricted to the limestone areas, or at least to these areas and their immediate vicinity. They reach thicknesses of several feet at various exposures, but like the quartz veins have not been found to continue horizontally for any considerable distance. It should be stated, however, that the lack of outcrops, due to the covering of loose weathered material or of moss, is a serious obstacle confronting the prospector who attempts to trace veins in this region, and makes it quite impossible without much labor and expense to determine their extent on the surface.

Numerous calcite veins are exposed in the limestone area of Anvil Mountain and its continuation east of Dry Creek. Prospect holes have been sunk on some of them and many have been staked as mining property. Free gold is found in small amount in some of these veins.

Besides the veins of quartz and calcite described above there are also veins made up of quartz, chlorite, and albite. These were observed most frequently in the Anvil-Newton Peak area.

No well-defined belt of mineralization has yet been established. There are restricted areas, nevertheless, where such secondary deposits are more highly developed than in the remaining parts of the region. The most important of these includes the upper portion of Anvil and Dexter creeks, the lower part of Glacier Creek, and a portion of Snake River extending north from Glacier Creek. Excavations on the third-beach line have shown that there also much of the schist bed rock is filled with small mineralized quartz veins. In this connection it may be stated that north of Rock Creek and on Pioneer Gulch gold is found in the surface débris, where concentration is due to decomposition of the bed rock and removal of the lighter material, the heavier constituents of the rock being left almost in place, since their movement is chiefly downward rather than in a lateral direction. In both places the bed rock is known to contain small mineralized quartz veins, and north of Rock Creek they carry sufficient gold to lead to some attempt at development. No unquestionably igneous rock bodies are known in this disturbed area. The greenstones either do not occur in any considerable amount or their identity is lost through alteration. One small exposure of greatly altered siliceous rock north of Specimen Gulch was at first considered to be an acidic granite, but there is much doubt concerning it.

Brooks (p. 25) emphasizes the fact that many of the most important placer deposits of the peninsula are found in localities where both

schists and limestones occur. In accounting for this he points to the contacts of different kinds of rock and the immediate vicinity of such contacts as loci of maximum weakness and greatest adjustment when the rocks are subjected to disturbing forces, as a result of which a freer circulation is there possible for mineral-bearing waters. This relation has been brought to the attention of the writer also by mining men in Nome and should be kept in mind by prospectors, since such contacts are favorable localities. Heavy limestones are found in the southern part of the mineralized area of Anvil and Glacier creeks, and thinner beds occur in the ridge between the two streams. To the northwest, however, their number decreases, and here some of the greatest mineralization is seen. It does not appear, then, that in this last-named place the presence of limestone was essential to the formation of mineral deposits. In fact, it would be difficult to prove that the limestone-schist contacts to the southeast are more highly mineralized than the schists themselves, but the occurrence of nearly all the placer-gold deposits of the peninsula in such areas suggests the relationship mentioned. Buster Creek affords a good example of a disturbed limestone-schist area where small secondary quartz deposits are numerous.

UNCONSOLIDATED DEPOSITS.

GENERAL DESCRIPTION.

Unconsolidated deposits may here be divided into two classes—those which have undergone a sorting process and deposition in water and those which have not. To the first class belong present stream and lake gravels, bench gravels, and the gravels of the Nome tundra; to the second, the loose débris mantling the slopes of hills and derived from the decomposition and weathering of the rock beneath or on the slopes above, together with part of the morainic material resulting from glacial action.

In by far the greater number of small streams the gravels consist of material like that of the hills surrounding the valley and appear to be entirely of local origin—that is, they are derived from bed rock in the drainage basin where they now lie and within a comparatively short distance of their present location.

In the larger streams, such as Nome, Snake, Stewart, and Sinuk rivers—that is, in streams heading toward the Kigluaik Mountains—together with a few of their tributaries, and in the Nome tundra a considerable portion of the gravel is derived from a more distant source, and its distribution is such as to indicate that part of it was laid down under conditions different from those prevailing at the present time.

Rounded granite bowlders derived from some source in the Kigluaik Mountains are found in Sinuk and Stewart River valleys, along Snake River, on Anvil and Dexter creeks, along Nome River, and at various

other localities at elevations as great as 800 or 900 feet, 1,400 feet in one place, above sea level. Such foreign fragments are rare if they occur at all in the deep elevated gravels at Dexter station, on the Nome Arctic Railway, but are numerous in the surface gravels at the head of Grass and Specimen gulches. They are often seen in the gravel deposits of Nome tundra, both at the surface and in the old beach deposits, where the fragments appear to be smaller and perhaps more rounded and weathered than those above. It is probable that much of the granite in the old beaches was brought by ordinary stream transportation or was carried along the shore from such localities as Cape Nome by the surf and ocean currents, and that most of the large surface bowlders were brought to their present location through the agency of ice, though in some places their position and quantity are such as to make it appear doubtful whether transportation by floating ice offers a complete explanation of their presence.

An examination of the deposits in the field therefore confirms the opinion concerning the character of the stream gravels which one would reach by a study of the maps alone—namely, that the gravels of the large southwestward, southward, and southeastward flowing streams show a greater variety of material than is seen on the smaller tributaries whose loose deposits are of more local origin. The fact which it is desired to bring out, however, is that on these small streams most of the gravels were laid down under present-day conditions such as will not account for the peculiarities and position of much of the gravels along the larger streams and of the elevated gravels. Two explanations have been suggested to account for such gravel accumulations as are found on the divides at the head of Dexter Creek, which in the saddle at Dexter station have a thickness of 135 feet. The first is that they are remnants of an extensive gravel sheet deposited at a time when the land had an elevation at least 600 feet lower than now and when the drainage systems may have been quite different. The second would account for their presence by considering them to have been deposited when the main stream valleys were occupied by glacial ice and the waters were ponded in some of the tributary streams. It does not seem possible, with the present knowledge, to say definitely that these gravel deposits are to be ascribed wholly to either cause, and it is not impossible that both conditions may have prevailed in some degree. The bed rock and pay streak at Dexter station, however, are such as to make it appear probable that the gold there was deposited by a southward-flowing stream or streams, since two well-defined stream channels at slightly different elevations lead from the head of Nekula Gulch through a bed-rock depression on the south toward Deer and Grouse gulches.

TUNDRA GRAVELS.

The Nome tundra gravels occupy the crescent-shaped lowland extending from Cape Nome to the hills west of Cripple River (see fig. 6), about half the area being within the boundaries of the district shown on the Nome special map. The tundra deposits were laid down in part by ocean currents and in part by streams, and consist of silt, interstratified fine sands, well-rounded gravels, and beds containing angular fragments and blocks up to 2 feet or more in greatest diameter. These large pieces are usually flattened slabs of schist, more rarely limestone. Large bowlders of granite, worn

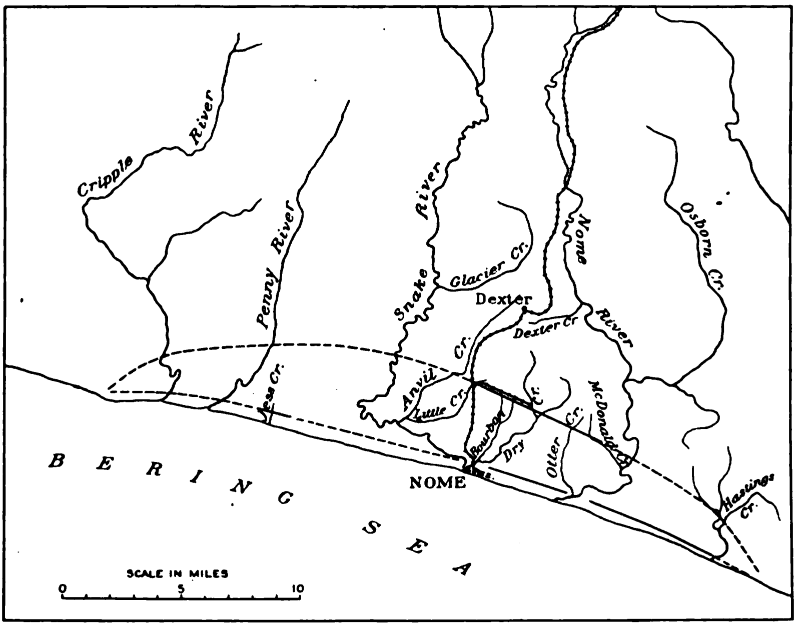

FIG. 6.—Sketch map showing the known parts of the second and third beaches (full lines) at Nome and their hypothetical continuations (dashed lines). The upper line also shows approximately the area of the Nome tundra.

and more or less rounded, are found on the surface, but were not observed in the coarse material below. Flattened and striated fragments of limestone are also found near the surface.

Our knowledge of the tundra has been greatly increased during the last two years by developments on the buried beaches. Two well-defined ancient gravel deposits of this sort have now been explored through a part of their length. (See fig. 6.) One of these, near Nome, lies about three-fourths of a mile north of the present coast line and extends eastward to a point within a short distance of Cape Nome. At Hastings Creek it is about a fourth of a mile distant from tide water, but east of that locality its position is not

known, and it appears to have been removed through erosion. To the west it is probably represented by the beach deposits of Jess Creek. Its elevation above sea level is 37 feet and its location is in most places indicated by a steep moss-covered gravel bank at whose foot it lies. The other beach line is definitely located from the place where it is crossed by the railroad tracks at Little Creek to McDonald Creek, a distance slightly more than 5 miles. Its elevation above sea level, according to reliable information obtained at Nome, is 79 feet. It extends in a nearly straight or slightly curved line between the points mentioned, yet shows slight undulations and is interrupted by the valleys of Nome River, Anvil Creek, and Snake River, these streams lying below its level. These two ancient coast lines are generally known as the second and third beaches, the present one being regarded as the first. Mention of others lying between is frequently heard, but although this is not only possible but even probable, no other continuous beach has yet been traced.

A generalized section of the deposits exposed along the third beach would show gravel or sandy gravel with coarse bowlders resting either on schist bed rock in which are a few limestone beds or, as is the case at the east end of the beach, on fine sands which in turn rest on schist bed rock. Above this is a considerable body of gravel overlain by "muck" and the surface vegetable matter. This general section is, however, subject to wide variations. The thickness of the muck varies from 1 or 2 feet to 20 feet or more. Underlying the muck in several shafts a blue clay was found. In places a heavy wash occurs near the surface. Here and there the gravels are slightly cemented by the deposition of lime or iron oxide. Marine gravels are interbedded with creek wash. The character of the material varies both in composition and in coarseness—in fact, the deposits where first exposed on Little Creek were so varied in appearance and manner of deposition as to cause doubt whether any of them were of marine origin.

The gold-bearing gravels or pay streaks vary in width from 25 to perhaps 100 feet and have a fairly constant southerly slope of about 1 foot in 10. They rest in some places on bed rock, in some places on other gravel, and toward the east, as has been stated, on fine sand.

Only a part of the shafts on the second beach have been sunk to bed rock, as the pay streak usually lies on a false bed rock of clay or sandy clay and gravel. There are few data, then, on which a complete generalized section could be based, but it appears that, though coarse angular material is by no means lacking, it is not as abundant as on the third-beach line. Furthermore, the quantity of garnet, or "ruby sand," is far greater on the second beach and the proportion of other sand and fine gravel is also greater. This is probably accounted for by the fact that much of the material of the third

beach has traveled a shorter distance from its source and has been less subject to stream and wave grinding.

In the third beach, then, irrespective of any greater differences which may have occurred in the meantime, we have definite proof that the land now stands not less than 79 feet higher than it did when the beach formed the coast line. Further evidence of elevation, though of lesser amount, is furnished by marine shells taken from various shafts between the second and third beaches. Such shells in an almost perfect state of preservation are found on Center Creek and suggest that in that locality they accumulated in comparatively quiet water. They occur in gravels 32 feet below the surface and at an elevation of about 20 feet above sea level. Numerous marine shells from Otter Creek were obtained at approximately the same height above sea but at a depth of 50 feet below the surface. They are in a good state of preservation.

As a rule the deposits of the beaches and of the tundra in general are frozen from top to bottom, but there are places where this is not the case. One such area is located near the intersection of the third beach and Holyoke Creek and has caused difficulty in working the Bessie Bench claim because of the large amount of water circulating through the gravel. The boundary between the thawed and frozen ground was here located by drilling, and care was taken not to bring the workings too close. Thawed ground is in some places overlain by frozen ground and here and there is underlain by it also. The reason for the presence of unfrozen areas is not entirely understood, but they are probably due in part at least to the circulation of water through the gravel.

These old beach lines indicate periods of temporary stability in an intermittently advancing or retreating coast line. It is possible that they mark the limits of encroachments of the sea at different periods, since in the case of the beaches mentioned the sea at the time of their formation was cutting fragmental deposits previously laid down. It is evident that if a sea floor gently sloping away from the land were gradually and uniformly raised, the beach line if affected by the elevation only would slowly move seaward, and that the beach deposits would be continuous from the time when elevation began till it ended. Such does not appear to have been the case on the Nome tundra.

The coast was not raised uniformly, and the upward movement may even have been interrupted by periods of depression. Nor are the tundra accumulations due to the work of the sea alone. Rivers and ocean both took part. Such streams as the Nome and Snake were already well established and spread their loads of loose material over the marine sediments at their mouths, carrying the shore line seaward and building up the lowland deposits. It seems probable, too, that

conditions such as prevail along the southern coast of Seward Peninsula to-day may have existed in the past and that the formation of lagoons shut off from the sea by sand bars, as may be seen east of Cape Nome and on a much smaller scale at localities like the mouths of Derby, Little Derby, and Cunningham creeks, may have taken place, and that these lagoons by subsequent filling may have played an important, though not the only, part in the construction of the Nome tundra.

This idea of the formation of the ancient beaches implies that the land formerly stood at a lower elevation, but it is also evident that it once had a greater elevation, for the rock valleys of Nome and Snake rivers are lower than the third-beach line at the places where they are crossed by it, and are even below the present sea level. The rock floor under the present beach also may have been above sea level when it was produced; it was surely little if any below it.

The formation of either of the old beaches was only an incident among the various changes which finally gave us the tundra as we see it to-day. A repetition of the same succession of events that led to the burial and preservation of the second and third beaches would in time add the present one to the tundra's treasury. From the geologist's standpoint these deposits are neither unique nor unusual. The concentration of heavy minerals by ocean waves is a commonly observed phenomenon, and it is only the value of the concentrated material which in this case brings the deposits to notice and makes them remarkable.

GLACIATION.

One of the difficult problems of the region is to discover what effect the action of glacial ice has had in modifying the former topography and in transporting loose material. That the upper valleys of nearly if not all the streams flowing south from the Kigluaik Mountains, as well as some of the tributary valleys of Grand Central River and Salmon Lake, have been occupied by ice masses in very recent time is beyond question. The morainic deposits at the head of Nome River indicate that at least the upper portion of that valley was occupied by ice, and several of the eastern tributaries of the river have well-formed cirquelike amphitheaters at their upper ends. There is no evidence available to show that the peninsula, or rather the southern portion of it, has ever been covered by an ice sheet. On the other hand, all the evidence seems to oppose that idea if our conceptions concerning the rate of rock weathering are correct. The occurrence of monumentlike rock masses, due to weathering, on the hilltops or slopes is one of the noticeable features of the region, and it seems extremely improbable that they could have withstood the advance of moving ice or that they could have been formed since the

disappearance of such ice unless it was present at a time very much earlier than the recent glaciation mentioned above.

Closer study of the region, however, especially of the distribution of gravels, has led to the observation of phenomena which are most easily explained as being due to ice action, and it may be that in valleys like that of Nome River ice streams from the Kigluaiks approached much nearer the coast than has heretofore been supposed. Since the evidence against a mantling ice sheet appears to be conclusive, it is altogether improbable that the tundra deposits have been affected in more than a minor degree by glacial ice except in the form of floating ice, for there are no known centers of local accumulation near the coast.

ECONOMIC GEOLOGY.

The progress in mining on Seward Peninsula has been presented from time to time in various publications of the Survey, and since this present form of report was adopted an account of each season's work has been published yearly. The economically important deposits may be divided into two classes—lode and placer deposits.

LODE DEPOSITS.

Some generalizations concerning the occurrence of veins have already been given and it now remains to describe in greater detail a few particular localities which have attracted some attention during the last year.

BISMUTH.

For a number of years bismuth has been known to be present on Charley Creek, a tributary of Sinuk River from the south. It was first found in the sluice boxes at the lower end of the creek, and later the float was discovered farther up and traced to its source. On the east branch of Charley Creek, at a point about 1,000 feet from the forks and at an elevation of 950 feet above sea level, two parallel quartz veins appear near the stream bed and have been found to carry the bismuth. These veins are about 12 inches and 8 inches in thickness and are separated by 16 to 18 inches of schist. They occur in strike joints dipping 50° to 60° N., and may be traced on the surface for only a short distance because of the covering of loose slide rock. At one place they are offset about 8 to 10 inches by a small fault. The percentage of bismuth seen in the veins is small, but some bowlders found in the stream below show a larger amount. Attempts to interest capital in the development of these veins have not been successful and up to the present time little has been done toward prospecting them.

ANTIMONY.

A quartz vein carrying the sulphides of iron and antimony was lately found on Manila Creek. The vein is located on the hill slope west of the upper end of the creek and as traced by surface float has a length of about 3,000 feet. It has an elevation above sea level of approximately 800 feet at its southwest end and 1,200 feet at its northeast end. Apparently it dips at a moderate angle toward the northwest. The thickness is not known, since at the time it was visited by the Survey party no exposure of the vein in place had been made and all information concerning it was derived from loose material on the surface, part of which may of course be considerably removed from its source. Pieces of the float, however, indicate that locally the vein reaches a width of 2½ feet, but that its average width is much less, probably about 8 or 9 inches. The best ore occurs as bunches or irregular streaks through the quartz and usually shows the reddish color resulting from partial oxidation or a stain of iron oxide. A prospect hole, supposedly on the dip of the vein, has been driven for a distance of 60 feet into the hill, but the vein was not visible at its lower end. The hole was located in loose surface material and schist bed rock considerably broken and so much displaced that it was not possible to make any reliable observation on the ore body. Besides antimony the vein carries some gold.

GOLD.

As yet no gold-bearing veins of proved value are known in the Nome region. The occurrence and character of quartz veins have been previously described, together with some general statements regarding them, and it was pointed out that the more highly mineralized veins are the small ones such as are numerous in the schists of the Anvil-Glacier Creek divide or the region north of Rock Creek. There was some prospecting on gold-bearing quartz veins in this vicinity during the summer of 1906, principally on the west side of Anvil Creek, above Specimen Gulch.

GRAPHITE.

Graphite occurs abundantly in portions of the schists included in both the Nome and Kigluaik series, but is not known in commercial amounts within the area covered by the Nome and Grand Central sheets. Just north of the Grand Central area, however, in the upper valleys of Grand Central River and Windy Creek, and especially in the vicinity of the divide between these two streams, there are graphite deposits of considerable size. Their occurrence, as well as that of the graphite to the west of Cobblestone River on the north side of the Kigluaik Range, has been known for a number of years, but so far no effort has been made to develop them.

Rising to the south from the saddle between the Grand Central and Windy Creek is a sharp ridge made up of biotite schists striking east and west and cut by dikes and sills of intruded coarse granitic rocks. Some of the schists are highly graphitic, the graphite appearing as abundant small scales on the cleavage surface and much of it not distinguishable from the biotite on casual examination. Locally graphite is segregated in beds of much flattened lenticular masses lying in the cleavage of the schist and reaching thicknesses of 6, 8, or even 18 inches. Thin beds of schist with numerous large garnets are included and quartz is nearly everywhere present. When compared with the higher grades of graphite the raw product of this locality is seen to have a much greater weight, owing to the included quartz.

As stated, the biotite schists are cut by sills and dikes of pegmatite. These also contain graphite, which is associated with them in such a way as to suggest that the intrusives and the graphite are closely related. Graphite seems to be an original mineral in the pegmatite and also occurs in close association with it in the schist. At one place about 8 inches of solid graphite was included between a pegmatite sill and the overlying schist. The steep slopes of the mountain are strewn with the loose fragments, which, owing to the fact that they are much lighter than either the schist or pegmatite, appear more abundantly on the surface. One block with dimensions of approximately 7 feet, 6 feet, and 30 inches consisted of about equal thicknesses of schist and apparently almost pure graphite.

These graphite-bearing schists extend eastward beyond the east fork of Grand Central River and westward across Windy Creek and the head of Cobblestone River to the region south of Imuruk Basin, where, if the reports of it are true, the graphite is present in greater quantity than in the locality just described.

The quality of this graphite is such as to prohibit its use where the better grades are required, although it might be of value for some purposes. With the present price of the mineral, however, it is doubtful if it can be now handled and placed on the market with profit.

PLACER DEPOSITS AND MINING.

To those who year by year have followed the development of mining in the region adjacent to Nome it is a noticeable fact that during the summer of 1906 the attention of mining men was largely given to operating within the area of the Nome tundra. This is a condition which may probably continue for some years, until the gold of the beaches begins to fail or until all the available ground is opened up. If, in addition to the operations on the tundra, those of Glacier Creek, Anvil Creek, and Grass Gulch are included, all the most important workings will have been taken into account, although elsewhere within the area shown on the Nome and Grand Central maps minor

operations were conducted on a few scattered streams, probably the most extensive being on Buster Creek.

At present the buried beaches of the Nome tundra occupy the center of the mining stage, and the efforts of all operators have been given to the exploitation of old placers or the search for new. Litigation touching the rights of property, however, has seriously obstructed the development of much of the most valuable ground, and may be expected to continue to do so as long as the present methods of acquiring and holding mining property are in force.

Mining is carried on most actively just now along the two ancient shore lines whose locations and principal features have already been described, but there has been more or less work on different streams, such as Dry and Bourbon creeks, and extensive drilling in various other parts of the tundra. On the first or present beach practically all work was suspended. Along the second beach many of the old properties were worked and some very good new ground was discovered in the vicinity of Otter Creek. The third beach is the principal producer of the region.

The third beach was discovered in the late fall or early winter of 1904, but when the summer closed in 1905 operations were confined to

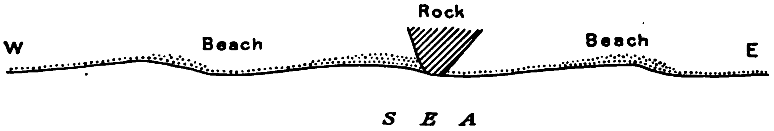

FIG. 7. Diagram showing the manner in which gold is concentrated north of Nome in shallow depressions or on sides of cusps of the third beach.

the immediate vicinity of Little Creek. An account of this locality has been published elsewhere.[a] During the winter of 1905-6 the eastward continuation of the beach was located to a point within a short distance of Nome River. Between Moonlight Creek or the railroad and McDonald Creek it is traced continuously. To the west and east of these localities it is not definitely known. Remarkably rich ground was exploited near Little Creek and between Holyoke and Bourbon creeks, and nearly all the claims between Little and Dry creeks have shown good values in gold. East of Dry Creek less work has been done, but most of the shafts have struck good pay. Nevertheless, some claims or parts of claims are of little value with the present cost of mining, for while the beach gravel deposits are continuous the pay in them is not so. There are intervals along the line where gold is present in small amount or is almost lacking. These places are sometimes referred to as "blanks." Further, the gold is not evenly distributed through any of the gravel. The writer was informed that in the shallow depressions such as occur at intervals along the beach a much greater concentration of gold took place on the east ends (see fig. 7), and that

[a] Moffit, Fred H., Gold mining on Seward Peninsula: Bull. U. S. Geol. Survey No. 284, 1906, p. 134.

in one or two places where low ridges or rolls of bed rock reached the surface and projected slightly beyond the ancient beach exceptional amounts of gold were found on their west sides, a position of maximum concentration corresponding to that in the indentations just mentioned. This would indicate that the distribution of gold in the gravels was largely influenced by the prevailing direction of the ocean waves and currents. It is probable also that very rich deposits, such as occur at Little Creek and Bessie Bench, are due to their nearness to the source of gold or to streams which brought it to the sea. The character of both the gold and the gravel accumulations would indicate the same thing. On the western part of the beach the gold is, on the average, much coarser than at the east end, where it resembles in appearance and approaches in fineness that of the present beach. The gravels of the west end are more variable in character and exhibit a larger amount of coarse angular stream wash than those toward the east, showing that the conditions under which the western gravels accumulated were less uniform—at one time stream deposits, at another sea deposits, being laid down.

Some ideas concerning the eastward and westward continuations of the third beach are suggested by an examination of the topographic map. The shore line must formerly have extended from the hills west of Cripple River to Cape Nome, and if one may judge by the portion now known it had the form of a broad arc of fairly uniform curvature, like the present beach, but with smaller radius. It is the belief of not a few miners at Nome that the third beach did not, like the first and second beaches, keep to the seaward of Cape Nome, but that it passed to the north through the broad, low depression between Saunders Creek and Flambeau River, thus forming an island of the Cape Nome granite area. The elevation of the depression between Cape Nome and Army Peak is only 115 feet, and the possibility of the cape being an island at the time when the third beach was formed can not be refuted by any evidence now at hand, although it appears improbable. Bed rock is traced northwestward from Cape Nome for a distance of nearly 5 miles, and in the low rounded hill between Hastings and Saunders creeks has an elevation of 297 feet. Between this point and the Army Peak schist mass, still farther to the northwest, is an interval of about 3 miles across a broad, low saddle where no rocks are exposed. As stated, the elevation of this flat at its lowest point is about 115 feet, but the depth of gravel is unknown. If it has a thickness of 40 or 50 feet it is possible that the third beach passes through. It seems far more probable, however, that the controlling influence in determining the coast line here was exercised by Cape Nome, since it must have been a factor in directing the ocean currents and consequently the accumulation of sands and gravel. To judge

from present conditions, it appears more likely that the sea would have built a connecting bar between Cape Nome and Army Peak rather than wash between them. At any rate, the force of the waves due to southerly and southeasterly winds would have been greatly diminished through the protection offered by Cape Nome, and the amount of concentration would have been thereby decreased.

Another idea which is maintained by some and may lead prospectors astray is that wherever bed rock can be found at an elevation of 79 feet above sea level the third beach will be present. The fallacy of this idea is immediately apparent when it is remembered that, so far as known, the old beaches were not laid down on a cleanly swept, somewhat uneven rock floor, but were formed over a surface whose inequalities had already been reduced by a filling of gravel and sand. This is shown by the fact that in many places they do not rest on bed rock, but are underlain by a variable thickness of loose deposits.

Further evidence of a somewhat negative character is afforded by the fact that neither the third beach nor either of the others is known to have formed reentrants at such places as their intersections with the valleys of Snake and Nome rivers, but rather that in each place where the river valleys lie below the beaches at such intersections the beaches end abruptly, for the present valleys through the loose deposits have been cut since the beaches were formed.

Another fact which must not be lost sight of in prospecting for the third beach is the possibility of recent warping. When formed, a beach is at sea level, and if raised uniformly throughout its length all parts will continue to have like relations to the sea. But changes of level do not always nor even usually take place in a uniform manner throughout all portions of an affected area. One part may be raised or lowered more than another, or one part may even be raised while another is sinking. It does not follow, therefore, that because one point of the beach has an elevation of 79 feet all other parts will have the same elevation, although in a small area such as this it is probable that they will not differ greatly.

Since, however, we now have no evidence that warping of any consequence has taken place, and since so far as we know it the third beach does maintain a fairly constant level, it is not to be expected that it will be found in any locality whose surface elevation is less than 75 or 80 feet above tide, even if such an area lies directly between or in line with points where it is known to be present.

Some probabilities concerning the distribution of gold in the known beaches or in others which may be found are gained from a consideration of its distribution in the gravels so far exploited. The richest gold-bearing gravels mined in the Nome tundra have been found in that portion of it which lies between Nome and Snake rivers. This

corresponds also with the richest part of the first or present beach, whose greatest values were taken from the neighborhood of the mouth of Snake River and from sands to the east toward the mouth of Nome River. This area lies directly south of the mineralized area from which it is believed that the gold has been chiefly derived, and it is the locality toward which weathered material from the near-by hills may properly be expected to migrate, since it lies immediately between them and the sea. There appears, therefore, to be warrant for the assumption that in the future, as in the past, the most valuable placers will be found within the limits given. One apparent exception is to be noted in the old beach placers of Hastings Creek. There is a possibility, however, that these may be the result of more than one concentration, that they may contain the gold of several old beach lines converging toward Cape Nome, and that the gravels from which they were derived may not originally have carried any very notable amount of gold.

GENERAL DEVELOPMENT.

Some improvements affecting in greater or less degree nearly the entire region were carried on during the summer and merit notice. Among them is the extension of the railroad formerly known as the Wild Goose, later as the Nome Arctic, and now as the Seward Peninsula Railway. In 1905 this road was extended from a point east of the summit of King Mountain into the low saddle north of it, near the part of the Miocene ditch known as the "Ex." In 1906 the road was continued northward and eastward through the valleys of Nome River and Salmon Lake and thence down the east side of Kruzgamepa or Pilgrim River. When the Survey party left Nome in October the roadbed was completed and the tracks were laid nearly as far as Lanes Landing, on Kuzitrin River. During the coming summer (1907) the road is expected to reach Kougarok River, thus opening for development a region which to this time has been one of the most difficult of access on Seward Peninsula.

The construction of the Seward and Pioneer ditches, which were begun in 1905, was carried forward in 1906, so that now both deliver water on the tundra north of Nome. The Seward ditch, the upper of the two, has an elevation of about 275 feet on Dry Creek. The Pioneer ditch is about 60 feet lower. There are, then, three ditches, the earliest being the Miocene, which supplies water on Glacier, Anvil, and Dexter creeks, bringing water from the upper Nome River drainage area to the vicinity of Nome.

A wood-stave pipe line to carry water from upper Grand Central River into the Nome River basin is under construction by the Wild Goose Company. The greater portion of the trench in which the

pipe is laid between the intake at Crater Lake and the Nome River-Grand Central divide is completed and about 1 mile of pipe put together. Part of the material for the remainder is on the ground, and more is being taken in this winter (1906–7). This line, if carried to Nome, as is now intended, will furnish water with greater head than any of the ditches yet constructed.

Construction work on the power plant at the outlet of Salmon Lake was interfered with by litigation between rival claimants for the dam site and water supply, but will doubtless be taken up again as soon as the question of ownership is settled.

GOLD FIELDS OF THE SOLOMON AND NIUKLUK RIVER BASINS.

By Philip S. Smith.

INTRODUCTION.

While the area drained by Solomon River and the Niukluk and its tributaries was visited by the writer for only a few days, it has seemed desirable to make a brief statement of some of the more important developments that have been under way since the progress report for 1905 was published.

SOLOMON RIVER BASIN.

DREDGING.

In the Solomon River region few new developments were in progress. The most active work was being conducted at the dredge near Rock Creek and at the Big Hurrah mine. Outfits of one to ten men have been engaged along the river and its main tributaries, but last summer was so dry that most of the smaller operators could work only intermittently.

The dredge on Solomon River has previously been fully described.[a] During the last season work has gone on uninterruptedly and, as far as could be learned, in a manner highly satisfactory to the owners. Much ground has been handled at a low cost. The dredge seems to be efficient in cleaning gold from the bed rock. This was a matter of a good deal of importance when the availability of a dredge was first discussed and is one of the vital points which should be thoroughly considered by anyone who contemplates undertaking dredging operations. Too much emphasis can not be placed on the preliminary investigations which should always precede the construction of a dredge, since the neglect of these considerations has often resulted in financial failure. It is not only necessary to have efficient management, but it is also of prime importance that the ground should be thoroughly prospected before a dredge is built. A dredge is a

[a] Moffit, Fred H., Gold mining on Seward Peninsula: Bull. U. S. Geol. Survey No. 284, 1906, pp. 136-137.

very costly machine, and unless an area of sufficient size and richness to repay the cost of the dredge and pay interest on the investment is obtained it is better not to consider this form of mining. It may seem a waste of time to state so self-evident a fact, but the number of abandoned dredges which have not paid for themselves in different parts of Seward Peninsula bears ample testimony to the neglect of this most simple precaution.

LODE MINING.

Work at the Big Hurrah mine on Big Hurrah Creek has continued during the past year on practically the same scale as formerly. No new developments had occurred at the time of the writer's visit. This mine still continues to be the only productive lode-gold mine in the entire district. About forty or forty-five men are employed at the mine and at the stamp mill, which is close to the mine.

PLACER MINING.

During the winter of 1905–6 work in the Solomon River region was carried on much more extensively than during the previous winter. It was recognized that the lower wages paid during the winter, coupled with the fact that the walls in deep gravel cuts stand better than when the frost is out of them in the summer and caving takes place, allowed the most economical development of many of the properties. From reliable sources it has been ascertained that approximately forty men were employed on Solomon River and its tributaries during the winter of 1905–6. Though no accurate figures could be obtained, it is estimated that about $75,000 was taken out during the winter. The figures for the production during the last summer are too vague to permit even an approximate statement.

NIUKLUK RIVER BASIN.

The areas in the Niukluk basin in which minerals of economic importance have been worked during the last year may be described according to their geographic position on the different tributaries of the river. The main productive tributary streams from the mouth of the Niukluk toward the head are Fox River, Melsing, Ophir, Goldbottom, and Elkhorn creeks, and Casadepaga River.

BENCH GRAVELS OF THE NIUKLUK.

In the whole region there are practically no winter mines, and this has a very detrimental effect on the growth of the district. The miners are driven to some of the other camps which offer winter work; and those who are faithful and industrious are retained in the field to which they have gone, and only those of lesser ability drift

back, after the break-up, to the summer work in the Niukluk region. This criticism applies only to the laboring men and is not intended in the least to reflect on the prospectors and miners who are developing their own ground or holding responsible positions with any of the larger companies.

To meet this annual exodus many of the more foresighted business men are attempting to develop winter workings which shall give employment to a more permanent population. Explorations with this end in view are being carried on in the deep gravels that occur along the Niukluk between Ophir and Camp creeks. This work has not progressed sufficiently to prove the value of the ground, but from the returns so far obtained further outlay is justifiable. During the last summer two men sunk a shaft 40 feet through these gravels. A section of this shaft is of interest not only as giving the succession of sands and gravels, but also as indicating the frozen conditions. The ice, on melting, so undermines and caves a shaft that its preservation during the summer is extremely expensive. The section in the shaft is as follows:

Section of bench gravels on Niukluk River between Ophir and Camp creeks.

	Feet.
Vegetation and muck	2
Pure ice	10
Sand and ice	15
Rock fragments, etc.; much mica	$\frac{1}{2}$
Sand and ice	1
Frozen gravel, carrying values	12

Up to the close of last summer no rich pay had been found in the benches along the Niukluk. Summer work in these benches will be costly and should be abandoned in favor of winter work.

FOX RIVER.

On Fox River some mining had been in progress during the past year, especially on I X L Gulch, a small tributary to Fox River 8 or 10 miles from Council. The rocks in the neighborhood are almost entirely schists and greenstones, but near Horton Creek there is a massive limestone member which forms a prominent topographic feature. The contact between the limestones and schists was not examined in detail and it is not known whether it is mineralized or not. The output from Fox River will be rather small, as the number of workers is limited.

MYSTERY CREEK.

On Mystery Creek, a small tributary of the Niukluk from the north, a small amount of gold has been won, but the work was conducted on a small scale.

BEAR CREEK.

The gravels which form the broad flat through which the Niukluk flows were prospected in the winter of 1905–6 on Bear Creek. Two shafts were sunk to a depth of about 50 feet, and fine sand, which was reported to be in many respects similar to beach sand, was found. The excitement attendant on the finding of old beaches in the Nome region has so stimulated the imagination of many of the prospectors that they see beach sand in all kinds of gravel. The so-called beach sand was not seen by the writer, and so no definite report can be made on the statement, which, if true, is of considerable importance in unraveling the complex history of the gold-bearing portions of Seward Peninsula. The scanty information at hand, however, leads to much doubt of the sea-beach origin of these sands. The reason for the doubt rests largely on the shape and size of the basin that would result if the whole region were depressed so as to bring the so-called beach down to sea level. Such a change would result in a narrow estuary, nowhere much over 4 miles in width, and in some places—as, for instance, 6 miles north of White Mountain—not over three-fourths of a mile. In such a body of water, wave and current action, the predominant activities in beach formation, would be very ineffective, and muds, silts, and river wash would be much more characteristic than clean beach sands. In this connection it is perhaps desirable to point out that the presence or absence of gold is in no measure dependent on sea beaches except under certain special conditions such as exist around Nome. The United States has a shore line composed of thousands of miles of beaches, and yet not 1 per cent of this entire length is auriferous in economic quantities. The idea, therefore, that old beaches and rich gold deposits are necessarily interchangeable terms should be discarded

MELSING CREEK.

On Melsing Creek, which was formerly one of the most productive streams in the district, not very much gold has been taken out during the last season. This was largely due to the extremely unfavorable weather conditions. It was so dry that only in the latter part of the season could enough water be obtained for mining purposes. When it did rain, so much water came down that it could not be handled by the miners, and consequently much of the rich ground was flooded. At the time of the writer's visit the only work in progress was near the junction of Basin and Melsing creeks. At this place the course of the pay streak, which lies only a few feet above the present stream level, is very sinuous and suggests that these gravels were laid down by a stream of relatively small size meandering widely on a flat slope. A feature of some interest was the occurrence of large granite and

quartzite bowlders, reaching 18 inches in diameter, in a layer of muck and decomposed vegetable matter lying above the gravels. The granite is but slightly decomposed and the bowlders are rather angular. These facts suggest a different transporting agent than running water. Associated with the auriferous gravels are in many places thin strata of cemented gravels in which the cementing material is mainly calcite. The cemented character prevents the separation of the gold in the sluice boxes, so that if much of this sort of gravel should be encountered recourse to some method of crushing would be necessary.

On Melsing Creek a method of preparing the sluice boxes which has not been seen in any other part of the peninsula was noted. This consisted of nailing a strip of canvas or cocoa matting on a plank slightly narrower than the bottom of the sluice box. On top of the canvas a strip of galvanized-iron screen, with about one-fourth inch mesh and the same width as the plank, was fastened. In use, this plank was placed in the bottom of the sluice box and the riffles laid on top, thus holding it in position. To clean, the plank was taken out of the sluice box, turned upside down, and pounded with a hammer or mallet. Although no comparative figures were available to prove the added efficiency of the sluice boxes thus equipped, the operator was completely satisfied with the results, as he was convinced that the additional saving of gold was very great. It is of course not necessary that every box in a set should be equipped with such a false bottom. Individual practice and study will determine the most effective number for different kinds of gold.

OPHIR CREEK.

Ophir Creek still continues to be the most productive of the tributaries of the Niukluk. The development of the placer claims along its course and on its main tributaries—such as Dutch, Crooked, and Sweetcake creeks—has constantly demanded additional water supply with greater head. To meet this demand high-level ditches have been constructed, but it was early recognized that even under the most favorable circumstances Ophir Creek could not be relied on to meet the growing demands. Consequently it has been necessary to lead water from other drainage areas into the Ophir Creek basin. The largest operation of this kind has been successfully carried out and undoubtedly permitted mining which the dry weather of last summer would have otherwise prohibited. This ditch takes water from Pargon River at Helen Creek, a small tributary about 2 miles north of the summit of Mount Chauik. The ditch is 11 miles long, nd in many places, where the slopes are excessive, flumes have been structed. The water is led around the eastern flank of Mount ik and thence across the divide into the Ophir Creek basin. In o obviate additional ditch construction, the water is discharged

into Ophir Creek and taken up again lower downstream by one of the existing ditches. It was estimated that about 8,000 miner's inches of water were available from the Pargon, but during the dry period of last summer only about 500 inches were delivered by the ditch.

Another project for leading water from Pargon River to Ophir Creek is under way, but as yet actual ditch construction has made little progress. Up to the present time the work of the company has been devoted mainly to surveying the course for the ditch, making preliminary observations, and acquiring rights of way. The proposed ditch will take water from a point considerably below the completed one, and for that reason should have more water available.

The operations on Ophir Creek during 1906 were carried on less by individuals and more by large companies than in previous years. The most active work had been done by the dredge at the "Portage," by elevators near Sweetcake and Dutch creeks, by derricks a little above Dutch Creek, and by shoveling in near the mouth of Crooked Creek. Above Crooked Creek no work has been done on Ophir Creek during the last summer. In regard to the tributaries it may be said that a little mining has been done on Sweetcake Creek, but the values do not seem to extend much more than a mile above its mouth. On Dutch Creek a little mining has also been done. The small stream joining Ophir Creek near claim "19 above" has been prospected, but does not seem to carry values above its mouth. Along Crooked Creek for a distance of 2 miles the creek has been worked continuously all summer by parties ranging in size from 2 to 14 men. The fact that almost all the side streams carry gold has led to an enrichment of the main-stream gravels. Practically every one of the bonanzas of Ophir Creek has occurred in the main stream at the junction of a side stream. The recognition of this feature, which also prevails on many other streams, should be of some assistance in prospecting undeveloped regions.

RICHTER, CAMP, AND GOLDBOTTOM CREEKS.

Richter Creek, the first tributary of the Niukluk from the southwest above Ophir Creek, although the goal of one of the stampedes that took place a few years ago, seems now to be exhausted and its output is negligible. Camp Creek has been worked by prospectors during the last summer, but the locations have been made mainly on the gravels near the Niukluk. The mine described on page 148 may be cited as an example of this kind of development. Goldbottom Creek and its branch, Warm Creek, tributary to the Niukluk a little above Camp Creek, have produced some placer gold during the last summer. Activities, however, have not been pushed with as much vigor as in previous years, only two or three small parties having been working on these creeks.

ELKHORN CREEK.

Elkhorn Creek has also been a small producer during the last year. The operations have been carried on for a distance of about 2 miles along the stream, but the largest amount of work has been done near the mouth. The section exposed in pits at the junction of the Niukluk and Elkhorn Creek is as follows:

Section at junction of Niukluk River and Elkhorn Creek.

	Feet.
Vegetation	2
Clay and muck	4
Sands and gravels	4

The lowest member showed considerable cross bedding in the sands associated with the gravels, thus indicating the variable character of the water by which they were deposited. Numerous pieces of wood in a more or less decomposed condition were found in the gravels. The surface form and internal structure suggest that the deposit is an alluvial fan of Elkhorn Creek rather than the flood plain of Niukluk River. Work on this creek was abandoned before the last week of September and, owing to the absence of miners, no estimate of the production or tenor of the gravels could be obtained.

CASADEPAGA RIVER.

MOUTH TO BONANZA CREEK.

The general impression of the mining which had been done along the Casadepaga in 1906 was that the work had been carried on more by prospectors than by active settled companies. As a result of this method of work the production from the stream and its tributaries will probably be small. On the lower course of the river as far as Bonanza Creek no mining had been in progress. Near Bonanza Creek two camps had been established to work the low bench gravels of the Casadepaga. These camps, however, have employed only two to five men each, so that not much work has been accomplished. A little work had been done on Bonanza Creek, but it was not visited.

BONANZA CREEK TO PENELOPE CREEK.

From Bonanza Creek to Penelope Creek the river gravels have been extensively prospected during the summer by a drill with a crew of six men, with the aim of determining the character of the ground. No statement as to the results of this work can yet be made. One peculiar feature noted in drilling below the mouth of Penelope Creek was that on certain of the river bars gold occurs on the surface and not on bed rock. There is no false bed rock of clay at these places and the surface concentration is due to the washing away of the gravels

of the bars during periods of flood, the particles of gold previously contained in the gravels being left behind because of their greater weight. On Big Four Creek, a tributary of the Casadepaga from the south between Bonanza and Penelope creeks, only assessment work has been done during the last summer. On Birch Creek, which flows into the Big Four about 5 miles above the Casadepaga, two camps have been engaged in working creek gravels below Shea Creek.

At Dixon Creek, 2 miles above Big Four Creek on the Casadepaga, there has been some development work. The bed rock at this place is schist and limestone, the creek appearing to follow the contact more or less closely. As this contact is in many other places the locus of mineralization it would seem desirable to further investigate the gravels of this creek and of the Casadepaga near its junction.

PENELOPE CREEK TO MOONLIGHT CREEK.

Penelope Creek is now the terminus of the Council City and Solomon River Railroad and by this line is about 32 miles from Solomon. There have been two camps on this creek, one near the mouth and one about a mile above. The upper camp has been the most active during the last summer. Four men have been employed and the gravel has been handled with horse scrapers. A short ditch has been constructed at a low level, but, as in other parts of the peninsula, considerable difficulty has been experienced from lack of water.

On Goose Creek only two men have been mining during the last summer and according to local reports not much more than wages has been produced. Three-fourths of a mile above Goose Creek there is a broad bench of gravels trenched by the Casadepaga which shows good values. Mining on this flat, however, has been inactive, pending the completion of a ditch from Moonlight Creek. (See p. 154.)

No mining except assessment work was done in 1906 on Canyon Creek. On Banner Creek also work was practically at a standstill. It is reported that all the gravels on the latter creek have been turned over and that the only values left are those that have been lost by the primitive methods in vogue when the creek was first worked. Certain claims are, however, held by annual assessment work, but the yield is seldom more than wages.

Willow Creek, which is noted on some of the Survey maps as Left Fork, is locally known as Lower Willow in order to distinguish it from Upper Willow Creek, also a tributary of the Casadepaga. Upper Willow Creek enters the river from the south about a mile west of Johnson Creek, while Lower Willow Creek has its mouth nearly opposite Ruby Creek. At the mouth of Lower Willow Creek two men have been working all summer. A mile above the mouth two men have been at work, but have been much hampered by the

lack of water. A mile above the forks of Wilson and Lower Willow creeks two men have been doing some work, but operations were suspended late in the season to allow the installation of a California grizzly. About 1½ miles above the fork of Wilson and Lower Willow creeks two men had been employed all summer. They stated, however, that the claim had been previously worked out, and their operations this summer consisted merely in saving some of the values that had been lost in the earlier mining. A short ditch at a low level takes water from the upper part of the creek and carries it to the discovery claims, a distance of about 2 miles. The geology of the region at the forks of Willow Creek is complex, the bed rock consisting of limestone and both chloritic and graphitic schist. The gold of this part of the stream has probably been derived from a near-by source. Mineralization is evident in at least two places at the schist and limestone contacts on the south side of Lower Willow Creek. At one place sulphides were recognized in a quartz vein, and numerous copper stains on weathered vein stuff were found on the summit of the divide between Lower Willow Creek and the Casadepaga near the head of Ptarmigan Creek.

On Ruby Creek two parties have been at work during the last summer, but the creek is now exhausted. It is said that the values have been more completely extracted from the gravels of this creek than from those of any other stream in the Casadepaga drainage, so that reworking these gravels in the future will not be remunerative.

On Moonlight Creek the main activity during the last two years has been ditch building. This creek heads in a series of bare limestone hills with steep slopes, so that the run-off is high. The ditch has an intake at an elevation of about 500 feet. It is proposed to carry the ditch across Canyon Creek to the broad bench of Casadepaga River about three-fourths of a mile southwest of Goose Creek. The water supply from Moonlight Creek will be augmented by a ditch line from Upper Willow Creek with its intake at such a level that it delivers water to the ditch at Moonlight Creek at an elevation of 500 feet. It is estimated that the ditch will have an average delivery of 1,500 to 2,000 inches of water.

An eighth of a mile below the junction of Moonlight Creek and the Casadepaga there has been some slight exploration of the bench gravels that occur a few feet above the level of the river. The gravels seem to be typical river gravels, but the floor on which they rest is rather uneven. Old channels have been reported in this district, but the rumors could not be investigated. Above Moonlight Creek there have been no mining operations on the Casadepaga during the last season.

AURIFEROUS LODE DISCOVERIES.

During the last few years there has been a noticeable increase in activity in the search for lode mines, with the result that several veins of promising character at the outcrop have been located. As has already been stated, the Big Hurrah mine is the only gold-bearing lode mine in operation in the district at the present time, but this condition can hardly prevail long.

DESCRIPTION OF LOCALITIES.

A very promising ledge of quartz has been located on the divide between Goldbottom and Ophir creeks near the head of Crooked Creek. The lode occurs near the contact of limestone and schist, and specimens show considerable free gold. It is reported to run nearly $40 to the ton, but it is not known how the sample was collected. This discovery seems to be very significant in connection with the fact that the gold in many parts of Crooked Creek is very sharp and angular and much of it has quartz fragments attached. A specimen of gold seen near the mouth of Crooked Creek, derived from a placer deposit at that place, was of such fragile shape and crystalline form that it seemed impossible for it to have been carried more than a few feet from the vein from which it was derived.

Another lode which has recently been found is located about half a mile southeast of Post Creek, a tributary of the Niukluk from the north. This vein has quartz as the gangue mineral, occurs at the contact of a schist and limestone, and is about 8 feet in width. According to reports it shows considerable free gold, and the values obtained by crushing and panning indicate that the vein would run nearly $35 to the ton. No responsibility is assumed for this statement, as it is not known how the sample was collected. It is an interesting speculation whether or not the vein on the divide at the head of Crooked Creek and this vein near Post Creek are connected.

Still another lode has been located on the south side of the Niukluk near the head of Camp Creek. No specimens were seen from this vein, and the descriptions were meager. They sufficed, however, to make it certain that a quartz vein carrying free gold in visible quantities has been found at this place and that developments are being pushed as efficiently as a small force and funds permit.

In addition to these well-authenticated finds, there are numerous rumors of other lode locations. These reports seem to indicate clearly that more and more attention is being paid to the search for lode deposits throughout the district.

ASSOCIATION OF LODES AND CONTACTS.

In view of the fact that all the lodes so far discovered are in close proximity to the limestone-schist contacts, it may be interesting to point out that Brooks, Collier, and Hess, in a manuscript which has not yet appeared in print, have suggested that these contacts may be zones of weakness along which ore-bearing solutions could most easily penetrate. If this suggestion is verified by subsequent closer inspection of a large number of examples, it will be of immense importance in directing the prospector to the more likely places of mineralization. It must be remembered, however, that in making so broad a generalization it is not intended to assert that in every place where a contact is found a deposit of economic importance will occur. The statement simply means that a valuable ore deposit is more likely to occur at such a place than at any other. If, however, the shattered and easily pervious condition which is so commonly associated with these contacts is duplicated elsewhere, ore deposits are just as likely to occur in those places as in the contact zone.

SILVER-LEAD ORE.

On Omalik Creek, a branch of Fish River, which is a tributary of the Niukluk, a silver-bearing galena lode has long been known. This vein was the first lode discovered in Seward Peninsula, and its discovery dates back to 1881. Since that time it has been worked more or less intermittently without producing much metal. During the last summer renewed attempts were made to reopen the vein. The mine was not visited by any member of the Geological Survey, but from the current reports it seemed to be the intention of the company to spend the summer months in taking in supplies, but active mining operations were not to be commenced until the freeze-up occurred. The high cost of supplies and labor makes this undertaking one of great expense.

GEOLOGY AND MINERAL RESOURCES OF IRON CREEK.

By Philip S. Smith.

INTRODUCTION.

Iron Creek, one of the largest tributaries of the Kruzgamepa, joins that river near the great bend about 11 miles east of Salmon Lake. Although really continuous, Iron Creek bears three names in different parts of its valley; thus from its mouth to Left Fork, a distance of 7 miles, the stream is called Iron Creek; above Left Fork as far as Eldorado Creek, a distance of 1 mile, it is called Dome Creek, and from Eldorado Creek to the divide it is called Telegram Creek. This confusion of names is due to the interpretation of the mining laws which permits the staking of additional claims on different creeks—i. e., creeks having different names. There are four main tributaries, the three largest being from the south and the fourth and smallest from the north.

Owing to the fact that some errors occur in the reconnaissance map of 1900,[a] the only map prepared by the Geological Survey of this region, it has seemed advisable to correct such inaccuracies as were noted in a hasty trip along the stream in 1906. Much assistance in platting the district was afforded by the transit notes of a ditch survey made by J. M. Love, of the Gold Beach Development Company. A corrected map of the Iron Creek basin is shown in fig. 8. It will be noted that this basin is roughly triangular. The western side of the triangle forms the divide between the drainage of the Kruzgamepa and that of Iron Creek. The southern side of the triangle in the western part separates the Iron Creek drainage from the headwaters of Gassman and Venetia creeks, both tributaries of Eldorado River. The divide from Venetia Creek is low, being only about 800 feet above the mouth of Iron Creek, or 1,000 feet above the sea, so that it affords a good route for a road to Nome. The eastern portion of the southern side of the triangle forms the divide between the Iron Creek and Casadepaga drainages. A low pass, with an elevation of about 1,000 feet, permits a good wagon road to run up Telegram Creek and down Lower Willow Creek to the Council City and Solomon River Railroad, a distance from the junction of Iron and Canyon creeks of 13 miles.

[a] Reconnaissances in Cape Nome and Norton Bay regions, Alaska, in 1900; a special publication of the U. S. Geol. Survey, 1901, pl. 17.

Now, however, that the Seward Peninsula Railway from Nome to the Kougarok has been completed beyond the mouth of Iron Creek, it is probable that with reasonable freight rates the use of the wagon roads will decrease, though freight is now delivered at Iron Creek by winter hauling from Nome for only 2 cents a pound. The northern side of the Iron Creek drainage basin forms the divide from Sherret Creek and several smaller streams which flow northward into the Kruzgamepa.

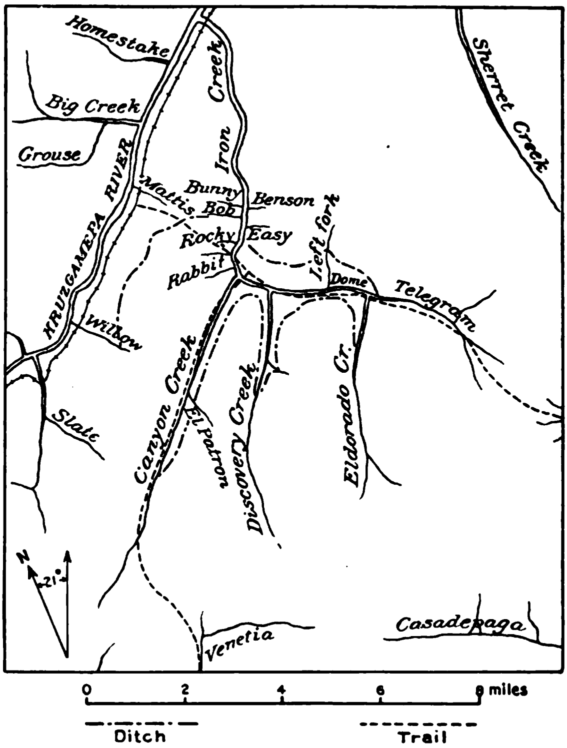

FIG. 8.—Sketch map of Iron Creek basin.

PHYSIOGRAPHY.

STAGES OF VALLEY CUTTING.

The physical features of the district are complex, and only the more striking facts can be presented here. An older topography, in which the present stream is intrenched, is preserved in the upper slopes of the valley walls. In this portion the bed rock is so covered over that exposures are practically wanting. This is due to a period of erosion and the accumulation of a heavy mantle of waste that reaches nearly to the top of the divide. The higher portions of the divides are generally bare, consisting of fantastically curved pinnacles of rock from

which taluses with steep slopes, practically uncovered by vegetation, descend, gradually merging with the smoother moss-covered slopes of the middle portion of the valley walls.

The streams in their lower courses flow in rock-walled canyons. In tracing any one of the streams headward the canyon is found to decrease in height and to merge gradually with the older topography previously mentioned. The history of these features suggests that the former topography of gentle slopes and wide, open valleys was produced by the long-continued erosion of rivers and weathering. Subsequently uplift of the region renewed the down-cutting power of the streams, so that canyons were carved in the floors of the old valleys. This erosion allowed rapid reassortment of the old gravels and waste and thus effected the concentration of any gold or other heavy minerals which may have been contained in the gravels.

The canyon cutting ceased, however, before it had progressed beyond the lower portions of the streams. The interruption was produced either by a movement of the land or, as is more probably the case, by a climatic change which decreased the amount of water transported by the streams. Such a change may have also been responsible for the disappearance of the local glaciers which were formerly present in the Kigluaik Mountains. Whether the climatic change had anything to do with the retreat of the glaciers or not is, however, of slight importance in this discussion. Some change must have occurred, for the streams are no longer down-cutting but actually building up the floors of their valleys. The reason for believing that the change must have been one which affected the rainfall rather than the elevation of the district with respect to sea level is based on the shape of the rock canyon. The canyon has a broad, swinging course which is so symmetrical that it could not have been produced by the straggling present stream, which occupies only a small portion of the floor between the rock walls. Many other streams in different parts of Seward Peninsula show this same feature. The extensive development of this phenomenon suggests a widespread cause, such as climatic change, rather than a local cause, such as uplift.

EVIDENCES OF GLACIATION.

Another feature of some theoretical interest is the presence of granite bowlders on the divide near the low sag at the head of Mattis Creek. In the rapid reconnaissance it was impossible to examine the district with sufficient care to make a final statement as to the origin of these bowlders. It is known, however, that there is no granite of similar character south of the Kigluaik Mountains. Furthermore, the granite bowlders are unweathered, showing that they have not been in their present position a very long time geologically. Although the question has not been carefully studied in the field, it is suggested that possibly

these bowlders have been brought by glaciers from Kigluaik Mountains and carried into their present position by ice blocks floating on a lake formed by glacial obstruction of the drainage. This suggestion is to be regarded only as a working hypothesis, but it fits in with the known facts, which may be summarized as follows: The angular, unweathered form and foreign character of the granite and the presence of shore lines at considerable elevations. Lakes of this type are common in regions that are at present glaciated, and evidences of such lakes have been recognized in many places where glaciers have now disappeared.

GENERAL GEOLOGY.

The bed rock of the district belongs to the Nome series. It consists of a series of much faulted and contorted limestones and schists and some greenstones. The greatest development of limestone occurs in the lower part of Iron Creek, but a great number of thinner beds interlaminated with schists are encountered even up to the headwaters. It is believed that the numerous alternations of schist and limestone are indicative of the source of the Iron Creek gold. Although no extensive proof of mineralization at the limestone-schist contacts has been found in this locality, the fact that such contacts are the loci of mineralization has been very well established in other parts of Seward Peninsula.

The rocks of the Iron Creek district trend northeast and southwest and dip toward the southeast, but there are numerous exceptions to this general direction, as the rocks are complexly folded and faulted. The deformation and consequent shattering that the rocks have undergone has undoubtedly resulted in the formation of zones of pervious rock in which mineralization has taken place. The streams also have taken advantage of the northeast-southwest structure and practically all the tributaries are arranged parallel to this direction.

In lithologic character the rocks are similar to the Nome series as described for other parts of the field. The schists present two main lithologic facies, namely, graphitic and chloritic. No boundary between the two can be drawn at the present time, although it is believed that detailed study would solve their interrelation and structure. The chloritic schists are most extensively developed in Iron Creek below Telegram Creek. They are thinly laminated, with wavy cleavage, and rusty brown to greenish gray in color. Chlorite and quartz are the only minerals distinguishable in the hand specimen. Graphitic schists are most abundant on Telegram Creek above Eldorado Creek. These rocks are in general but slightly schistose and would better be described as dark, nearly black, graphitic quartzites, with here and there schistose phases. Hand specimens show considerable quartz and a little chlorite. The other constituents are not distinguishable by the eye, though the presence of graphite is recognized

by its soiling the hands. Here and there some sulphides are found, especially in the places where dislocations occur.

The greenstones which occur in the Iron Creek region have not been studied in detail, but seem to be similar to those found in the adjacent country nearer Nome. If this correlation is correct, they are mainly of intrusive origin. Rumors were heard of an extrusive flow of greenstone south of Iron Creek, but neither was it found in place nor was any float of an extrusive greenstone seen, so that doubt is felt about the occurrence of a surface flow.

MINING DEVELOPMENTS.

GENERAL CONDITIONS.

Mining on Iron Creek has been much retarded by the inaccessibility of the region, but this obstacle is now disappearing with the building of railroads and wagon roads. Freight from Nome can now be delivered by the Seward Peninsula Railway at the mouth of Iron Creek, but the schedule of rates was not learned. It has already been noted that in winter supplies can be brought in by team at a cost of 2 cents a pound. The cost of summer hauling by team to Iron Creek is now, owing to the good condition of the road to Nome, but little higher than the winter rate.

DITCH CONSTRUCTION.

In 1906 work on Iron Creek and its tributaries had almost ceased at the time of the writer's visit in the latter part of September. With one exception the work for the season seemed to have been carried on by small outfits of only one to five men each, and a liberal estimate of the output of the creek and tributaries for the year would not exceed $50,000. The most important work during the last season has been ditch construction, about 13 miles having been built. One ditch taps Eldorado Creek at a point 1 mile above its junction with Telegraph Creek and leads the water along the south wall of Iron Creek to a penstock near the junction of Discovery and Iron creeks. A second ditch takes water from Canyon Creek 5 miles above its mouth and leads it along the east wall of Iron Creek, thence following the south slope of the valley to the west side of Discovery Creek, along which it runs southward to a point 2 miles above the mouth of the stream, where it crosses and extends along the east side of the valley to the penstock previously noted. Another ditch on the north side of Iron Creek, which takes its water from the junction of Telegram and Eldorado creeks, is also being constructed by the same company. Between sixty and seventy men at a time have been employed in the construction of these ditches. They were not completed until the latter part of September, so that water for washing the gravels was available for

only about two weeks. The ground operated at present by the company is on Iron Creek at the mouth of Discovery Creek. A hydraulic elevator has been installed to handle the flood-plain gravels, and active mining operations will be conducted during the coming year.

MINING ON MAIN STREAM.

Between Discovery Creek and Left Fork on Iron Creek there is a fractional claim which has been worked for the last two years on a small scale. From one to five men have been employed on this claim all summer. The gold is coarse and easily saved. Both rusty and bright gold are found. The values occur in a thin pay streak on limestone and in the cracks and crevices of this bed rock. The small amount of ground in this claim has prevented any large-scale developments.

At the junction of Left Fork and Iron Creek three men have been continuously employed all summer working creek gravels. The method of working these gravels has been by means of a bed-rock drain and sluice boxes. Several nuggets worth $30 or $40 each have been found in this place. The bed rock is a much shattered limestone with thin bands of chloritic schist both above and below it.

A short distance upstream from Left Fork the largest nugget recorded from Iron Creek was found. This nugget weighed over 30 ounces and was valued at $600 on the assumption that the gold was worth $18.50 an ounce. It is a fact of some significance that upstream from this point, which is about half a mile above Left Fork, the gold is all rusty, whereas below both rusty and bright gold occur. The reason for the absence of bright gold above is believed to be that this point marks the place where the older and newer valleys merge. In other words, upstream the creek flows in the nearly unmodified old valley, while downstream it has cut below that level. The result of the down cutting has been to wear some of the gold and expose fresh, shiny surfaces; whereas the gold that has been practically unmoved has a rusty coating.

Between Left Fork and Eldorado Creek only one camp was in operation in 1906. Five or six men have been at work at this place, but as it is understood that this portion of the creek has already been worked over three times it is doubtful whether subsequent work will be remunerative. The gravels are apparently similar to those already noted.

Above Eldorado Creek the main stream, as has been previously stated, is called Telegram Creek. One man only has been at work on this stream during the last year. This claim is located at a point about a mile from the divide. The bed rock is mostly graphitic schist with some thin limestone and schist bands. Several nuggets, worth as much as $100 apiece, have been found on this claim, and it is reported that very coarse gold is found even on the crest of the divide from Willow Creek. The water supply of Telegram Creek is small,

especially in a dry year, such as 1906. Often this lack has hindered or in large measure prevented exploration of the gold gravels that have been found by prospectors in this part of the Iron Creek basin.

MINING ON TRIBUTARIES.

On the tributaries of Iron Creek but little work has been done. Bunny Creek, the fifth stream which enters from the west below Canyon Creek, is not over three-fourths of a mile in length. Two men have done a little work on this stream last summer, but it probably produced not more that $100 or $200. On Bobs Creek, the next small stream south of Bunny Creek, the only work done during the last season has been on the upper part. This claim has been worked with water brought over the divide from Willow Creek, the first tributary of the Kruzgamepa east of Rock and Slate creeks. Considerable trouble has been experienced with the ditch, as a large part of it is built on frozen ground, which melts under the water. This ditch carries only about 400 miner's inches of water. Even this small amount is more than is yielded throughout the season by Willow Creek, and it is proposed to extend the ditch next year 3 or 4 miles to Slate Creek.

Easy Creek, which enters Iron Creek from the east opposite Bobs Creek, has shown good values in the lower portion. Three men were at work at this place last summer, but it closed down rather early in the season owing to the drought. Little more than assessment work has been done on the other claims along Easy Creek. The next small stream to the south is Lulu or Benson Creek. Four men have been operating on this creek the entire summer. On Rapid, Rocky, and Rabbit creeks, the three other small tributaries of Iron Creek from the west below Canyon Creek, little more than assessment work has been done during the last season, although they are completely staked.

Except on Canyon Creek, no work has been done on any of the larger tributaries of Iron Creek. On a little tributary of Canyon Creek called El Patron Creek, about 3 miles above the junction with Iron Creek, one man has been at work all summer. However, but very little gold has been produced owing to the lack of water. It is expected that with the completion of the Canyon Creek ditch water may be purchased, so that work will be pushed with greater activity in the coming summer.

SUMMARY.

In summarizing the Iron Creek region it may be said that the gold is mostly coarse and easily saved; that it has been derived from a relatively local source; that water for the economic development of the placers is at hand, and that the questions of freighting and transportation are rapidly being effectively and satisfactorily settled.

THE KOUGAROK REGION.

By Alfred H. Brooks.

INTRODUCTION.

"Kougarok district" is the name[a] generally given to an auriferous gravel region lying in the central part of Seward Peninsula and drained, for the most part, by Kougarok River. This paper will describe, besides the drainage basin of the Kougarok, the other gold-bearing streams tributary to Kuzitrin River. Investigations were begun in this field in 1900 by the writer,[b] assisted by A. J. Collier, soon after the first actual discovery of workable placers, and were extended by Mr. Collier[c] in the following year. In 1903 the district was reexamined by Messrs. Collier and Hess, who prepared a statement for a report not yet in print.[d] The writer was again in this field in 1906, spending about ten days in visiting some of the more important localities. The notes of Messrs. Collier and Hess have been freely drawn upon, but for the conclusions here advanced the writer is alone responsible. All of the surveys thus far made have been preliminary, and the data obtained leave much to be desired, both as to the details of the geology and the distribution of the placer gold.

TOPOGRAPHY.

The northwestern front of the Bendeleben Mountains slopes off to a lowland basin, 20 miles long and 10 miles wide. On the southwest the basin walls gradually approach each other and finally constrict the valley to a width of about 3 miles, but 10 miles below it opens out again to the low ground encircling the east end of Imuruk Basin, or Salt Lake, as it is popularly called. The north wall of the lowland basin slopes up gently to an upland, whose flat summits stand at altitudes of 800 to 1,600 feet. Here broad, flat-topped interstream areas, diversified by some higher domes reaching altitudes of 2,500 feet, are separated by wide valleys. As elsewhere in the peninsula, the upland summits mark a former stage of erosion. After the entire

[a] The "Kougarok precinct" includes the entire drainage basin of Kuzitrin and Kruzgamepa rivers.

[b] Brooks, A. H., assisted by G. B. Richardson and A. J. Collier: A reconnaissance of the Cape Nome and adjacent gold fields of Seward Peninsula (in Reconnaissances in the Cape Nome and Norton Bay region, Alaska, in 1900, a special publication of the U. S. Geol. Survey, 1901).

[c] Collier, A. J., A reconnaissance of the northwestern portion of Seward Peninsula: Prof. Paper U. S. Geol. Survey No. 2, 1902.

[d] Collier, A. J., Hess, F. L., and Brooks, A. H., The gold placers of a part of Seward Peninsula (in preparation).

region was planated, uplift formed a plateau, which is deeply dissected by the present watercourses.

Kuzitrin River carries the drainage of the district southwestward to Imuruk Basin, a tidal inlet connected with the sea at Port Clarence.

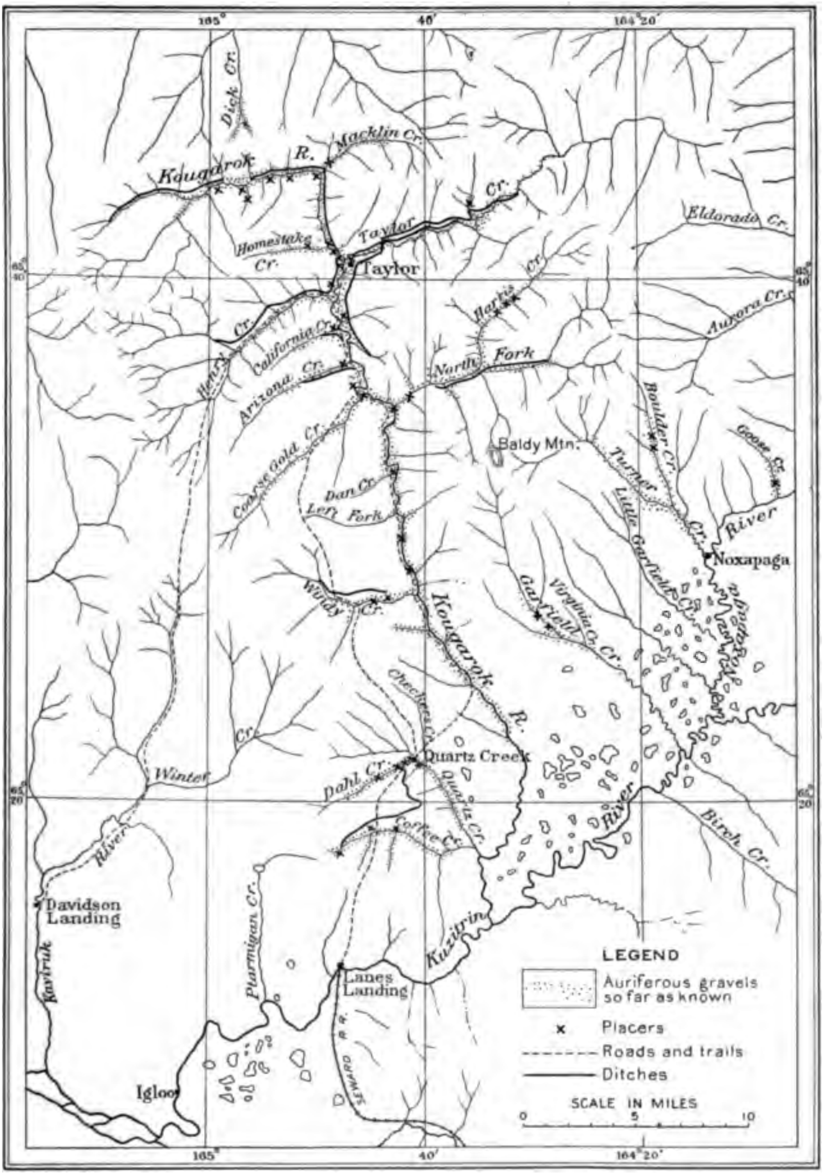

FIG. 9.—Sketch map of Kougarok region.

This river meanders with sluggish current across the lowland basin already described, receiving numerous large tributaries from the

north, the longest being Noxapaga and Kougarok rivers and Garfield Creek. (See fig. 9.) A number of smaller streams heading in the Bendeleben Mountains are confluent from the south, but these are outside of the province here discussed. The northern tributaries find their sources in the upland region, through which they meander in valleys which have tortuous courses and whose walls are in many places broken by well-defined benches, many of them covered with gravel. Though the topographic features described show no great variety in character of the relief, there is abundant evidence that the physiographic history of the region was far more complex than this simple analysis would indicate. There were no doubt at least two and probably more epochs of planation. Moreover, the benches along the valley walls bear evidence that the uplift which brought about the incision of the present valleys was intermittent.

As elsewhere in the peninsula, the dominant vegetation is moss. Timber is entirely absent, but thick growths of alder and willow are found along the watercourses. Grass, though not abundant, occurs in favored localities along the valley floors. The hill slopes are usually moss covered, with here and there some grass. Only on the highest summits and in sharply cut valleys is bed rock exposed, a feature of the region which makes it exceedingly difficult to decipher its geology.

GEOLOGY.

The stratigraphic units described in the reports referred to—the Kigluaik and the Nome series, including a subordinate member of the latter, known as the Port Clarence limestone—are represented in the Kougarok region. The limestone, schists, and granites of the Kigluaik series go to make up the Bendeleben Mountains, which stretch along the southern margin of the field here described. So far as known, these rocks have not been found to be gold bearing and need no further mention here.

This older series is separated by a broad belt of alluvium, flooring the Kuzitrin Valley, from the schists and limestones of the Nome series, which form the country rock of the uplands and are also the source of the placer gold. Here the Nome series is clearly divisible into two groups—(1) limestone and (2) a succession of graphitic phyllites and mica and greenstone schists, with some beds of semicrystalline limestone. The schist series is closely folded and faulted, and its stratigraphic relation to the massive limestone has not been definitely established. Collier's interpretation of the known facts leads him to the opinion that the limestone is the younger formation, while, on the other hand, the writer is inclined to the belief that the schists overlie the limestone. The latter view finds support in the

fact that Moffit,[a] in the adjacent region to the northeast, found a schist series resting on a massive limestone formation.

Be the stratigraphic relations what they may, the fact of the occurrence of two series, one essentially schistose and the other a massive limestone, is well established. The limestone occurs in one area with oval outline lying between Kougarok and Noxapaga rivers, and in another of more irregular contour between Kougarok and American rivers. Between these two limestone belts lie the schists, which here exhibit great irregularity of dip, being closely folded and faulted.

Besides the sediments above described, several types of igneous rocks occur in this region or immediately adjacent to it. Greenstone schists, which are probably altered intrusives, occur with the schistose rocks. Dioritic rocks, some of them massive, others more or less schistose, are not uncommon among the schists as dikes and small stocks. A large stock of granite occurs a few miles northeast of the Kougarok-Arctic divide. There is a noteworthy hot spring near the margin of this granite mass. In the upper Kuzitrin Valley a large area is occupied by a basalt lava stream of recent age.

As in the other placer districts of the peninsula, the schistose rocks appear to be the source of the placer gold. Quartz seams and small veins are common in the schists and many of them are iron stained. Reports from prospectors indicate that some of these veins carry gold, but, so far as known to the writer, no lodes of commercial value have yet been found. It is said that a copper-bearing lode has been found in this district.

There appears to have been two generations of quartz intrusives. The earlier of these was injected previous to the extensive deformation of the schists, for its veins are crushed and sheared. The later intrusion, which cuts the first system of veins and is comparatively little deformed, appears to be more commonly mineralized than the first. The presence of the recent granite intrusion at a near-by locality suggests a genetic relation between the second generation of quartz and the granite, but of this there is no proof.

This district lends additional support to the view elsewhere set forth (pp. 25, 130–132), that the locus of mineralization lies at or near the contact between the schists and the limestones. There appears to be a close correspondence between the limestone and schist contacts and the distribution of the placer gold, so far as determined.

The alluvial deposits fall into three groups—(1) stream and river gravels; (2) the gravels, sands, and clays which floor the basin lowlands; and (3) bench sands and gravels. Glaciation has taken place in the Bendeleben Mountains, but there is no evidence that these ice masses ever crossed the Kuzitrin Valley to the upland on the north.

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[a] Moffit, F. H., The Fairhaven gold placers: Bull. U. S. Geol. Survey No. 247, 1905.

It is quite possible, however, that the basin of the Kuzitrin may have been in part covered by glacial ice at one time.

The stream and river gravels, which constitute the best-known type, vary in character according to their place of occurrence. The developed placers are nearly all in the stream and river gravels. So far as known they carry, as a rule, only material derived from the basins in which they are found. Much of the material is well rounded, but that of the pay streaks in the placers is in many places subangular. Quartz usually dominates as a constituent of the pebbles. In some streams, such as Kuzitrin River, the gravel bars are made up of iron-stained quartz, almost to the exclusion of all other material. Sands and some clay occur interbedded with the stream gravels, forming, however, but a small percentage of the bulk of the alluvium. In all the smaller streams and in parts of the larger ones a bed of clay or sandy clay, in which more or less vegetable matter is intermingled, forms the topmost layer. This surface bed, which varies in thickness from 2 to 30 feet and is called by the miners "tundra," appears to be a subaerial accumulation, due in part to the decay of vegetable matter and in part to the deposition of silts during the rainy season. Though sometimes explained as a lake deposit by the miners, its distribution and character seem to preclude lacustrine origin.

The gravels, sands, and clays of the basin lowlands, forming the second type of alluvium, are known only where exposed by river erosion. At such places they consist of material identical in every way with that of the first group except that the material is somewhat finer. Some fragmentary evidence furnished by drill records goes to indicate that much of the basin is filled by clay deposits whose genesis can probably be best explained by lacustrine action. The determination of the outline of this old lake and of the cause of its formation must await further investigation. It is worthy of mention, however, that the surface deposits of gravel and sand in the Kuzitrin basin probably as a rule do not exceed 20 or 30 feet in depth. This, however, applies only to the basin, for in the constricted part of the valley the gravel deposits probably have a much greater depth.

Bench gravels are of common occurrence in the district. The best known are those along the main Kougarok between Taylor and Windy creeks, and these have proved to be auriferous. Similar deposits occur on the upper Kougarok, but have been little prospected. These bench gravels are of the same character as the alluvium of the present streams. The sands and gravels which form the extensive bench at the mouth of Quartz Creek and continuing up that stream to Dahl Creek are described on page 173.

Another type of surficial deposit that deserves mention is the ground ice, which here occurs more extensively than in the Nome region. Along the southern slopes of the valleys it forms in many places almost

continuous beds for several miles. It varies in consistency from a frozen mud to almost pure ice. Fragments of beaver-gnawed wood have been found in this ice at a number of places. The ice beds usually slope with the valley wall, and some of them extend up the hillside to a height of 100 feet above the stream. This ice can probably best be explained by the accumulation and subsequent solidification of winter snow, which has become buried by the talus and alluvium. The thick coat of moss, once established, effectually prevents the thawing of the ice. Ground ice is a perpetual source of trouble and expense to the ditch builders.

DEVELOPMENT.

This district was probably visited by prospectors as early as the summer of 1899, though claims were first staked during the winter of 1899–1900, and it is unlikely that any actual discovery of gold was made until the following summer. A rush from Nome to the new field took place in March, 1900, and another in July of the same year. Harris Creek appears to have been the scene of the first claim staking in March, and in July gold was found on Quartz and Garfield creeks. In August and September considerable gold was taken out of the shallow placers of these two creeks. In the meantime gold had been found on the main Kougarok and many of its tributaries, but no claims were opened up. In 1901 there was a decrease in the gold output, for the shallow diggings were rapidly exhausted and no very rich gold had been found on other creeks. The remoteness of this field from transportation discouraged prospectors except those with good financial backing. There were no bonanzas to give an impetus to mining. Probably the most important discoveries were those of Kougarok River, but these could be exploited by the individual miners only during low stages of the water, and sudden freshets often destroyed the work of weeks of preparation. Thus the mining interests in the Kougarok district may be said to have lain dormant for several years, though some gold was produced every year, chiefly on Dahl Creek. With the successful construction of ditches at Nome came a renewed interest in this outlying placer field. In 1903 T. T. Lane constructed a ditch from the head of Coffee Creek to a bench at the mouth of Dahl Creek, and this was the first long ditch in the district. In the following years many more ditches were planned and surveyed. In 1905 and 1906 ditch construction went on with feverish activity, and by the end of last summer upward of a hundred miles of ditch were planned, about half being completed. The larger ditches can be enumerated as follows:

The North Star ditch extends from Arctic Creek, on the east side of the Kougarok, to the mouth of Taylor Creek and up that stream about 10 miles, with a total length of 15.2 miles. The Cascade ditch takes

water from Taylor Creek, about 6 miles up, and discharges at the mouth of the creek. Both these ditches were completed in 1906. The Kougarok Mining and Ditch Company had one ditch in operation in 1906 and two more partly constructed. Of these the Homestake ditch, which heads on the Kougarok 3½ miles above Macklin Creek and discharges at the mouth of Homestake Creek, with a head of 172 feet, was completed in 1905. Work has been begun on the Altoona ditch, which heads 1¼ miles above the mouth of Washington Creek. A third ditch has been located, to be built up Macklin Creek, taking water from Schlitz and Reindeer creeks north of the Arctic divide. T. T. Lane has completed a ditch from Henry Creek, discharging at Homestake Creek. All the above-mentioned ditches discharge within a few miles of one another on Kougarok River and represent an aggregate outlay that hardly seems warranted by the developments in placer mining.

The Irving Mining Company has constructed a ditch from Washington Creek along the north slope of the Kougarok Valley nearly to the mouth of Mascot Creek. Another ditch that has been built on North Fork by the Northwestern Mining Company heads at the junction of Alder and French creeks and is to be built to the Kougarok, about 7 miles being completed in 1906. The Lane ditch, from Coffee Creek to the mouth of Dahl Creek, has already been mentioned. Smaller ditches have been built or surveyed at various places, including Arizona, California, Coarse Gold, and Windy creeks. Besides these, there are many other schemes for ditch building which have not gone far enough to deserve individual mention.

The summer of 1906, being abnormally dry, was especially favorable for ditch construction, but worked havoc with those who were prepared to sluice. It is perhaps well, however, that the managers of the large companies should know what they may expect and be able to include an allowance for a dry season in their estimate of cost. The records show that in the last seven years there have been two notably dry summers (1900 and 1906) and that therefore the last season is not by any means as abnormal as some promoters would try to make the public believe.

Up to 1906 the Kougarok district could be reached from Nome only by an overland journey of about 100 miles or by a very circuitous water route via Teller, Imuruk Basin, and Kuzitrin River. From Lanes Landing, at the head of scow navigation on the Kuzitrin, freighting by wagon to the creeks cost from 6 to 15 cents a pound, the winter rates being much lower. J. M. Davidson and Andrew J. Stone, who are among the largest operators in the district, have established a transshipping point on Kaviruk River,[a] called Davidson Landing, and built a road from this place to the upper Kougarok region, a distance of 40 miles. Small lighters can be towed directly from the

[a] Called locally Marys River.

ship's side at Port Clarence to Davidson Landing, so that at least one handling of freight is avoided.

In 1906 the Seward Peninsula Railway was extended northward to the head of Nome River and then down the Kruzgamepa to Lanes Landing. Surveys have been made looking to a further extension of this line up the Kougarok Valley. This railway will bring the district into close touch with Nome and will do much to accelerate its development. The recording office now at Igloo, 7 miles below Lanes Landing, will in all probability be moved to a more accessible point on the railway.

Mining operations in 1906 may be summarized as follows: One hydraulic plant was operated for a part of the season on a bench claim on Dahl Creek and two on the main Kougarok River above the mouth of Taylor Creek. The two latter utilized the plant to remove the overburden and part of the pay streak, bed rock being cleaned by hand. In both cases hydraulic lifts were operated. Considerable work was done on the lower four claims on Dahl Creek by shoveling into sluice boxes. Ground sluicing was done by a number of operators, notably on Windy Creek and on Solomon Creek, a tributary of Taylor Creek. Several claims were worked in a small way on Coffee Creek and on some of the tributaries of the Kougarok.

A dozen outfits were engaged in mining the river gravels and some of the tributary gulches of the Kougarok above Macklin Creek, but were handicapped during the earlier part of the season by lack of water and later by excess of water, which flooded them out. Below Taylor Creek, on the main Kougarok, attempts were made to exploit the bench gravels either by sinking shafts and drifting or by the aid of small hydraulic plants, but in most places the equipment was insufficient to produce anything more than meager results. Probably the most successful of these operations was the drifting on some benches on the west side of the Kougarok near the mouth of Taylor Creek. Harris, Garfield, and other creeks received some attention. Chiefly owing to the inadequacy of the water supply it is unlikely that there were, all told, over 150 or 200 men engaged in productive mining in this region.

It is thought that the amount expended in ditches and purchase of claims during the last two years (1905-6) probably exceeds a million dollars. Such an expenditure hardly seems justified by the placer ground actually proved. The total gold output, including that of 1905, is estimated at $585,000, distributed probably about as follows:

Gold production of Kougarok district, 1900-1905.

1900	$50,000	1904	$150,000
1901	35,000	1905	200,000
1902	50,000		
1903	100,000		585,000

This amount is, however, only an approximation. It should be noted that this does not include the output of the entire Kougarok precinct, but only that part of the precinct which is described in this paper. The production of 1906[a] was very small, owing to the lack of water.

DISTRIBUTION OF AURIFEROUS GRAVELS.

To speak broadly, the auriferous gravels thus far discovered in the district fall into two zones which converge from lower Kougarok River. (See map, fig. 9, p. 165.) The larger zone, here termed the "Kougarok belt," stretches northward and embraces much of the Kougarok basin; the smaller zone, which appears less well defined, extends eastward to the Noxapaga, embracing the streams tributary to Kuzitrin River. This second zone will here be called the "southern belt." The Kougarok belt lies in a zone of schistose rocks, bounded on either side by the massive limestones. It furnishes, therefore, further evidence for the general law that the gold has its source at or near the limestone and schist contacts. Nor does the southern belt, so far as known, offer an exception to this rule. Each of these two belts embraces placers of the various types to be described below.

SOUTHERN BELT.

GENERAL DESCRIPTION.

The auriferous gravels forming a broken fringe along the southern margin of the highlands which bound the Kuzitrin basin on the north and west have certain features in common which justify the description of them as a unit. This belt includes the placers of Quartz and Garfield creeks, as well as those of the Noxapaga basin.

The bed-rock geology of this belt is obscured, both by the extensive alluvial deposits and by the products of deep rock decay. It appears however, that a belt of graphitic phyllites and schists, including some calcareous matter, stretches across the upland lying between Kaviruk and Kuzitrin rivers. In many places these rocks carry quartz veins, some of which are stained with mica and quartz. Schists occur north of the graphitic rocks, and still farther north these give way to a limestone. Though it is impossible to delineate these formations exactly because of the deeply weathered character of the rocks and the absence of outcrops, yet it appears that most of the gold-bearing creeks cross the contact of the limestone and schist.

The unconsolidated formations embrace (1) the present stream gravels, (2) the deposits flooring the Kuzitrin lowland, and (3) the bench gravels. Of the first group, which embraces most of the work-

[a] Not a single operator in the district responded to a request for information in reference to production.

ing placers of the district, little need be said, as they are fully described on page 168. Little can be added to the description of the second group already given. The terrace gravels merit some closer consideration.

It has already been indicated that the upland region falls off from an altitude of about 1,100 feet to the Kuzitrin Valley floor (100 feet above sea level) by a gentle slope, here and there broken by a more or less well-marked terrace. The best defined of these terraces lies about 100 feet above the present water level and is traceable from the mouth of Quartz Creek northward along the west side of Kougarok River to the point where the valley of the river emerges from the upland. A similar feature is found along the northern margin of the Kuzitrin lowland, and the lower part of Turner Creek and some of the tributaries of the Noxapaga are reported by Collier to be incised in deep gravel deposits, indicating an easterly extension of this same feature. Where exposed, the alluvium of which these terraces are made up is nearly everywhere seen to be composed of the same character of material—i. e., well-rounded and stratified brown sands and gravels. Certain exceptions to this will be noted below. There can be no doubt that these benches are the remnants of an extensive gravel sheet. In support of this view are the hillocks made up of stratified gravels which here and there stand above the floor of the Kuzitrin lowland.

Near the mouth of Quartz Creek the top of the terrace is about 125 feet above the water and the gravels rest on clay of unknown thickness about 15 feet below water level. The exposed material consists of well-rounded gravel and sand. On going up Quartz Creek the surface of the gravel is seen to dip with the grade of the stream, and a mile below Dahl Creek about 100 feet of gravel and sand is exposed in the valley wall. Above this point this bed was not definitely recognized, but it is believed to be represented by a white quartz gravel that is exposed on Quartz Creek just below the mouth of Dahl Creek. On the north side of Dahl Creek valley a shaft sunk to a depth of 180 feet was entirely in this white gravel and did not reach bed rock. It appears probable that these white gravels are a phase of the bench gravels of lower Quartz Creek and the Kougarok described above. The surface of these white gravels dips to the northwest under the trench occupied by Dahl Creek. In other words, the gravels underlying the pay streak at the Lane hydraulic mine and those of Dahl Creek are a part of the same bed. The surface of this same gravel deposit is believed to be exposed near the mouth of Joe Creek, a tributary of Quartz Creek. These relations are too complex to permit detailed analysis here, but they point to the following conclusions: (1) The auriferous gravels of the Lane hydraulic mine, Dahl Creek, and Joe Creek constitute the same horizon; (2) they are underlain by

alluvium, forming the white gravels of Dahl Creek and the bench gravels of the lower part of Quartz Creek and of the Kougarok, and these same gravels are found along the front of the upland near Garfield and Turner creeks; (3) this older gravel series is not believed to carry values, though it is known to be more or less auriferous.

This last conclusion is borne out both by the prospecting and by theoretical considerations. In general the rich placers of the peninsula occur in alluvium which is subangular and which was deposited under conditions of subaerial decay rather than during floods. These bench gravels are, however, well rounded and stratified and appear to have been laid down during periods of flood, which are not favorable to a concentration of values.

So far as known to the writer, the base of these gravels on bed rock has never been prospected. There is no reason to believe that the basement member may not be gold bearing, and in the opinion of the writer the chances of finding gold at depth is sufficiently good to warrant the outlay of the cost of prospecting them to bed rock.

Though it is not proposed to describe them in detail, a few notes on the different creeks will be appended.

COFFEE CREEK.

A peculiar auriferous deposit was opened up during the winter of 1906 on the upper part of Coffee Creek. Some rich placer ground was found in the angular talus of the valley slope, which appeared to be almost in place. The gold occurs in 4 to 7 feet of angular schist and quartz débris and weathered schist bed rock covered by 18 to 20 feet of muck. The quartz is iron stained, but does not appear to be auriferous, and the gold probably came from the schist. The gold is angular, spongy, and bright colored. These facts indicate that the material mined is the decomposed surface of a mineralized zone. The deposit has been traced about 1,000 feet, but being buried deeply its boundaries are not well known. It is indicative of the source of the gold and suggests at least the possibility of finding lode deposits which may carry values.

The other placers of the upper part of Coffee Creek are, as a rule, buried under an overburden of muck 10 to 20 feet thick. The gravels are chiefly schist and vary from 3 to 7 feet in thickness. Bench gravels similar to those of lower Quartz Creek occur near the mouth of Coffee Creek and are here said to carry some gold.

DAHL CREEK.

A bench at the mouth of Dahl Creek, 20 feet above the present stream bed, has been a large producer. A section at this point is as follows:

Section at mouth of Dahl Creek.

	Feet.
Muck	20
Ferruginous gold-bearing gravel	3–4
Sticky clay	½–1
Barren white quartz gravel.	

The section of the creek placers is practically the same, for as already stated the two horizons are believed to be identical. A mile and a half above the mouth the lower gravels give way to bed rock, and above this point but few values have been found.

QUARTZ CREEK.

Quartz Creek for half a mile below the mouth of Dahl Creek appears to have been worked out, for no mining has been done there for several years. As yet no values have been found below this point. Some placer ground has been developed at the mouth of Joe Creek, but the pay streak does not appear to be extensive.

TRIBUTARIES OF KUZITRIN RIVER ABOVE THE KOUGAROK.

This portion of the field, though the scene of profitable mining in the early days of the camp, has advanced but little in recent years. This is in part because the placers were found to be neither as extensive nor as rich as first believed and in part because of the high costs of mining due to the inaccessibility of the creeks.

Garfield Creek, from which $25,000 in gold was taken out during the first two years after its discovery, has been almost abandoned, though one claim continues to yield a little. The pay streak on this creek was narrow and thin and rested on a clay bed rock. Benches, though present, have not been found to carry values. So far as known, hard bed rock has never been reached in any of the operations.

Boulder Creek, a tributary of Turner Creek, has had a history similar to that of Garfield Creek. Little work has been done on it during recent years. From 3 to 11 feet of gravels are reported, with no bed rock. Deeper prospecting would appear to be justified. Among the smaller creeks in this vicinity on which gold has been found, but which have not been developed, are Grouse, Black, and Goose creeks.

NORTHERN BELT.

GENERAL DESCRIPTION.

The auriferous gravels of the main Kougarok above the Kuzitrin flats and of its tributaries form the northern belt of placers. The bed rock of this area is chiefly schist, but most of the tributaries of the Kougarok have their courses in limestone areas. This belt embraces stream placers and bench placers, of which the former type, to the present time, has yielded most of the gold. There are two forms of

stream placers—(1) those of the smaller gulches and creeks and (2) those of the main river. The gulch and creek placers are usually of small extent, but are so situated that many of them have been profitably mined by pick and shovel. On the other hand, many of the placers of the main river are of considerable extent and are difficult to exploit except with equipment that permits the handling of a large amount of material and provides for both high-water and low-water conditions.

Bench gravels have been reported at various localities, but those of proved economic importance are confined to the main Kougarok River and some of its larger tributaries. These are chiefly within 25 feet of the present water level, but some higher benches are reported to be auriferous.

KOUGAROK RIVER.

The Kougarok is a swiftly flowing stream carrying at its mouth 10,000 to 15,000 inches of water and having an average gradient of about 20 feet per mile. Most of the material transported is coarse, varying from fine gravel to coarse cobblestone.

Undoubtedly the most extensive deposit of auriferous alluvium yet found in the district is that of the main Kougarok, occurring both in the present stream bed and on the benches. For at least 40 miles of its course the gravels of this stream have been found to be auriferous, though it is impossible to state at present what part of these carry commercial values. The valley of the Kougarok has a meandering course and varies greatly in its cross section. In some places it is steep walled, narrow, and without benches; in others it opens out into a broader basin, with gentle slopes or bounded by well-marked rock benches. A striking feature of its topography consists of the various levels of erosion, which are marked by benches both along the main river and along many of its tributaries. These clearly indicate a succession of uplifts that have brought about the incision of former valley floors, remnants of which are preserved as benches. Evidences were observed of at least three of these uplifts, of which naturally the last is best preserved, and consists of a rock bench covered by gravels standing 15 to 25 feet above the present water level. Where the Kougarok enters the Kuzitrin lowland both valley walls show well-marked benches. Two levels are here marked—one at 50 feet and one at 25 feet. These are traceable for about a mile and a half above Windy Creek; then the walls become steeper, and as far as Left Fork the river occupies a canyon-like valley. From this point to Washington Creek, 20 miles above, some evidence of benching can be observed at most places, though it is not intended to imply that the benches are continuous. The individual benches have not been traced, but in that part of the valley which lies below Taylor Creek there are at least two levels and possibly three.

Some of the placers of the present stream bed have been worked spasmodically since the discovery of the district. A little gold has been taken out of the river bed with shovel and rockers near Coarse Gold Creek and at various points as far as Taylor Creek. Much more work has been done at and above the big bend of the Kougarok, near the mouth of Macklin Creek, and as far as Washington Creek. Mining was necessarily confined to low-water stages. These placers are in no sense of the river-bar type, as they carry coarse gold mingled with gravels and concentrated to a large degree on bed rock.

The river gravels in their upper part are usually well rounded and stratified, but the pay streak near bed rock is in many places made up of subangular material. The largest pebbles are usually not over 1 or 2 feet in diameter, but a few bowlders of greater size, which have been contributed by the talus of the valley slopes, are encountered. No general statement of the thickness of the gravels can be made, as it varies greatly in different parts of the river. In the canyon previously described bed rock is exposed throughout the river bed. In many places above the canyon gravels are almost entirely absent, while in other places the depth to bed rock is 6 to 20 feet.

The width of the alluvial floor also is variable, for in some parts of the river the entire valley floor is buried in gravels, and in others the stream has uncovered bed rock over a part of the floor. The actual flood plain of the river varies from 100 to 800 feet in width. Where the river enters the flat it is about 800 feet wide; in the canyon, about 100 feet; at the mouth of North Fork, about 300 or 400 feet; at the mouth of Taylor Creek and near the mouth of Trinity Creek, about 300 feet.

Below the flat at the mouth of Taylor Creek the alluvium is almost entirely made up of gravel; above that point the gravels are in places buried under considerable muck.

So far as known to the writer the gold found in the stream bed below Coarse Gold Creek is chiefly fine, but at the mouth of this creek and above it considerable coarse gold is reported. This fact is important, because it indicates that in the upper half of the river enrichment has taken place from local sources and that the gold has not all been brought in by the main stream from its headwaters. Coarse gold is, however, reported to occur at the mouth of North Fork.

The gold of the flood plain is usually of a dark color; that of the smaller tributaries is bright. Thus far the only placers of the flood plains that have been opened up on a commercial basis are those at the mouth of North Fork, where little has been done, at the mouths of Taylor and Homestake creeks, and between Macklin and Washington creeks.

The bench deposits of the Kougarok appear to afford an attractive field for the gold miner. Their position makes them easy of access, and no hydraulic lifts are required to dispose of the tailings. These benches can not be described in detail, because the facts are wanting. Between Coarse Gold and Taylor creeks the benches are particularly well defined, and there are at least two distinct levels about 25 and 50 feet above the water. So far as observed the gravels are from 8 to 10 feet in depth and are usually covered with muck. No determinations of values are known to the writer, but the fact that some gravels of the lower tier have been worked at a profit by crude methods makes it seem probable that their gold content is not inconsiderable.

Bench gravels have been reported at various places above Taylor Creek, and some are known to be auriferous, but they have not been developed on a commercial scale.

This rather fragmentary evidence points to a wide distribution of gold along the main Kougarok and to the presence of values at many places in both the bench and the flood-plain gravels. From the existing knowledge it appears that this valley contains the largest gold reserve of the district.

WINDY CREEK.

The developed placers on Windy Creek occur in a small tributary from the south called Anderson Gulch, which is a minor depression in the valley wall. The gravels exposed in the cuts are 2 to 3 feet thick. In addition to this 1½ to 2 feet of bed rock is put through the sluice boxes. The bed rock is a silvery mica schist with much iron-stained quartz. These placers have been traced for 1,600 feet along the slope of the valley of Windy Creek. The known area of workable deposits is not large, but as gold has been found in other parts of the basin other placers will probably be found.

NORTH FORK.

The basin of North Fork was the scene of the first gold discoveries in the Kougarok district, and some of the placers have yielded a considerable output of gold. A marked feature of its topography are the benches, of which three different tiers are known. The bed rock of the basin includes both schists and limestones.

Workable placers have been found on the main stream and on Harris Creek, and gold is reported from the gravels of Eureka Creek and a number of other small tributaries. The evidence at hand indicates that this basin will become an important producer.

COARSE GOLD AND OTHER SMALL CREEKS.

The alluvium of Coarse Gold Creek is auriferous, but as yet only a small amount of gold has been extracted. A hard diorite forms the bed rock of a part of the creek and does not afford a favorable surface for the concentration of values. The lower part of the creek is in schist and deserves attention on the part of prospectors.

Arizona and California creeks are small streams, but they have considerable gravel deposits near their mouths. Both the flood-plain and bench deposits have yielded considerable gold.

Gold was discovered on Henry Creek about five years ago, but the values do not appear to be great. Little has been done on this stream since 1903.

Between Coarse Gold and Taylor creeks there are a number of small gulches which have yielded values, but these will probably be mined with the bench deposits already described and deserve no special mention here.

TAYLOR, HOMESTAKE, AND OTHER CREEKS.

Taylor Creek is the largest tributary of the Kougarok. In its basin are exposed both limestone and schists. Some mining has been done near the mouth of the creek, where the placer deposits are similar to the flood-plain deposits of the Kougarok, of which they form an extension. Above this point the only mining attempted in this basin is on a small tributary called Solomon Creek. At the mouth of this stream there is a sloping bench on which lie 3 to 7 feet of gravels covered by 8 to 10 feet of muck. These gravels are auriferous and have been mined in a small way, as have also the stream gravels of Solomon Creek half a mile above.

Auriferous gravels have been found throughout the length of Homestake Creek, and the claims near the mouth have produced some gold. The auriferous gravels are from 5 to 8 feet thick, and pay streaks to a width of 40 feet have been found.

Among the smaller tributaries above Homestake Creek which have yielded values are Macklin, Trinity, and Mascot creeks. These streams contain no extensive deposits, but include some workable gravels, whose occurrence is of significance in showing a wide distribution of the gold.

CONCLUSIONS.

The investigations on which this report is based were entirely too inadequate to permit a final word on the value of the auriferous gravels of the district. That there are extensive alluvial deposits carrying sufficiently high values to yield adequate returns for economic mining no one can deny who has studied the matter carefully.

It is equally well known that as yet, with the exception of a few claims, no gravels of very high grade have been developed. Certain conditions already referred to are favorable to the probable extension of the placer-mining industry. One of these is the wide extent of the mineralization. If, as stated elsewhere in this report (pp. 25, 130–132), the zones of mineralization of the peninsula are most commonly found along or near the contacts of mica schist and limestone, the Kougarok is a region where placers should be expected. As in other mineral-bearing districts of the peninsula, the bed rock is closely folded, faulted, and fractured, and mineralized quartz stringers are not uncommon, but have not been tested as to their gold content. In at least two localities the gold has been traced to its bed-rock source in the schists. So far as the present studies can determine, the bed rock is no less favorable for the occurrence of gold here than in other districts of the peninsula.

The history of this province since it was last elevated above the sea, interpreted according to theories elsewhere presented, favors the concentration of gold in the alluvial deposits. The various epochs of erosion indicated by the bench deposits would promote the concentration of the heavier materials in the gravels. In several localities on Kougarok River the gold was probably derived by reconcentration from older elevated placers. Yet it must be said that, in spite of this reconcentration, the resulting placers have not been found to be as rich as those of similar origin in other parts of the peninsula. This fact points toward the conclusion that the bed-rock source is not as heavily mineralized as in some of the other districts. The lower bench gravels of the Kougarok and some of its tributaries are undoubtedly among the most important deposits of the district, if only because of their favorable position for cheap mining. The highest gravels (i. e., those above 50 or 60 feet) reported at various places have now little prospect of development unless they are far richer than any of the other deposits. Their topographic position makes it difficult, if not impossible, to hydraulic except at great cost. Experience has shown that the abundance of the ground ice, the limestone masses, and heavy talus all combine to make ditch construction and maintenance expensive.

The writer is unable to make a definite statement of the gold tenor of the gravels in this field, for the results of the little prospecting that has been done have not been available for the purposes of this report. When the meager evidence is carefully weighed, it seems probable that $2 to the cubic yard must be considered high value for most of the placers of the district. Whether or not there are considerable bodies of gravel which carry such values, the writer is not prepared to state. While a gold tenor of $2 would be considered very rich in most placer camps, it is low compared with that of some of the auriferous gravels

of Anvil and Ophir creeks. Nevertheless, there is no doubt that gravels can be profitably mined at but a fraction of this amount in many places in this district.

The two dry summers, 1900 and 1906, make it evident that such climatic conditions must be reckoned with in counting cost, especially where large investments of money are made. Though during a wet season there is an abundance of water, nevertheless the Kougarok has no such reservoirs to draw on as the Kigluaik Mountains, which are being tapped by the Nome ditches, and this fact is emphasized by a dry season like that of 1906. At the rate that ditch building is going on every possible source of water supply will soon have been utilized. Here, as elsewhere, more careful prospecting of the ground would probably have curtailed some of the ditch building. It appears that some operators have been too ready to believe without adequate prospecting that the values in the ground were sufficient to warrant large expenditures for ditch construction. This hit-or-miss style of mining has fewer odds against it in regions where the hope of finding bonanzas is better than in the Kougarok. It certainly can find no place in a region where the question of costs has to be carefully considered.

The Kougarok does not appear to be an inviting field for the miner without capital. Though considerable gold has been recovered by pick and shovel, on the whole the values thus far developed are not high enough to yield profits by such simple methods of mining. This is certainly true now, but conditions may alter with the reduction of costs of labor and supplies.

To recapitulate briefly, the following facts appear to be established: (1) Prospecting up to the present time, so far as known to the writer, has not established the existence of many bonanzas. (2) There are some extensive deposits of heavy auriferous gravels, yet it appears that but few of them have been sufficiently prospected to prove their values. (3) Water is far from abundant, but, in many localities during most seasons, is probably sufficient. (4) Mineralization, however, is widespread, as is also the gold in the alluvium. (5) Some of the bench deposits are very favorably located for profitable exploitation by hydraulic methods. (6) There is probably some ground which can be dredged, but as yet few facts in regard to it are available.

In the opinion of the writer the Kougarok district will become one of the important gold producers of the peninsula, though it is not to be expected that its output will ever be comparable to that of some of the older districts, such as Nome and Ophir Creek. It is a field where profits can be expected only by a careful counting of costs and conservative business management.

WATER SUPPLY OF NOME REGION, SEWARD PENINSULA, 1906.

By J. C. Hoyt and F. F. Henshaw.

INTRODUCTION.

The economic working of the richer placer deposits in all portions of Alaska depends largely on the amount of water available for both washing and hydraulicking the gold-bearing gravels. The scarcity of water has led to extensive ditch construction, which has often been undertaken with but little exact information in regard to the available water supply. Many of these hydraulic works have been either financial or engineering failures, owing to insufficiency of water, and some of these failures could have been averted had reliable hydrographic data been at hand.

For this reason the United States Geological Survey started systematic measurements of the flow of Alaska streams during the summer of 1906. Owing to the smallness of the funds available the work was confined to Seward Peninsula, and especially to the streams from which water could be taken for working the rich placers near Nome, as shown on the Nome and Grand Central special topographic sheets. This area was chosen for investigation on account of its extensive operations.

These investigations consisted in (*a*) determining both the total flow and the distribution of the flow of various streams during the mining season; (*b*) collecting facts in regard to general conditions affecting water supply; and (*c*) gathering statistics in regard to the diversion and use of water.

GAGING STATIONS.

Measurements of discharge were made at the forty-five different gaging stations named in the subjoined list. Most of these stations are on streams so located as to be available for the placer gravel near Nome.

Gaging stations on Seward Peninsula.

1. Nome River above Miocene intake.
2. Buffalo Creek.
3. Dorothy Creek.
4. Miocene ditch at Black Point.
5. Miocene ditch at flume.
6. Hobson Creek at Miocene ditch crossing.
7. David Creek ditch intake.
8. Seward ditch intake.
9. Grand Central River (North Fork) at elevation 750 feet.
10. Grand Central River (North Fork) at elevation 1,030 feet.
11. Grand Central River (West Fork) at elevation 860 feet.
12. Grand Central River (West Fork) at elevation 1,010 feet.
13. Crater Lake outlet.
14. Grand Central River below forks.
15. Grand Central River below Nugget Creek.
16. Gold Run.
17. Thompson Creek.
18. Nugget Creek.
19. Copper Creek.
20. Jett Creek.
21. Morning Call Creek.
22. Kruzgamepa River at outlet of Salmon Lake.
23. Crater Creek.
24. Iron Creek below mouth of Canyon Creek.
25. Iron (Dome) Creek.
26. Eldorado Creek.
27. Discovery Creek.
28. Canyon Creek.
29. Sinuk River.
30. Windy Creek.
31. North Star Creek.
32. Stewart River.
33. Slate Creek.
34. Josie Creek.
35. Irene Creek.
36. Jessie Creek.
37. Upper Oregon Creek.
38. Slate Creek.
39. Aurora Creek.
40. Penny River at elevation 420 feet.
41. Penny River at elevation 120 feet.
42. Eldorado River.
43. Fall Creek.
44. Glacier Creek.
45. Snow Gulch.

MEASUREMENTS.

The detailed results of these measurements are given in Water-Supply Paper No. 196, from which the accompanying tables, indicating the general conditions, have been taken. Table 1 shows the mean weekly water supply available during 1906 for use back of Nome. Table 2 gives the mean monthly run-off per square mile

above various stations. Table 3 gives the minimum flow for streams rising in the foothills and in the mountainous regions. These tables not only show the amount of water available in the area under investigation, but also give a basis for estimating the possible water supply to be had in other similar areas.

TABLE 1.—*Mean weekly water supply, in second-feet, available for use back of Nome, 1906.*

Date.	Available for use at elevation 250 to 275 feet, Nome River low level.	Available for use at elevation 400 to 450 feet.				Total.
		Nome River high level.	Upper Grand Central River, Thompson Creek, and Gold Run.	Nugget, Copper, and Jett creeks.	Sinuk River, Windy and North Star creeks.	
July 1-7	31	45	153	7	88	324
July 8-14	110	144	343	26	173	796
July 15-21	36	58	179	15	90	378
July 22-28	29	49	156	12	79	325
July 29-August 4	22	42	101	8	50	223
August 5-11	26	45	108	8	49	236
August 12-18	34	53	91	8	42	228
August 19-25	58	84	138	10	62	352
August 26-September 1	94	128	202	22	94	540
September 2-9	48	73	101	14	51	287
September 9-18	33	53	68	9	36	199
September 18-30	86	118	250	20	125	599
Mean	51	74	158	13	78	375
Maximum	110	144	343	26	173	796
Minimum	22	42	68	7	36	199

TABLE 2.—*Mean run-off at various gaging stations on Seward Peninsula.*

Station.	Drainage area (square miles).	Mean run-off (second-feet per square mile).				
		July 1-31.	July 1-4 and 11-31.	August 1-31.	September 1-30.	September 1-18.
Grand Central River (North Fork), elevation 750 feet	5.4	....	[a] 7.53	6.80	....	5.85
Grand Central River (North Fork), elevation 1,030 feet	2.3	....	....	11.9	....	9.65
Grand Central River (West Fork), elevation 860 feet	5.4	....	10.3	6.02	....	4.72
Grand Central River (West Fork), elevation 1,010 feet	2.8	....	9.64	4.96	....	3.36
Crater Lake outlet	1.8	....	10.8	6.56	....	2.89
Thompson Creek	2.5	....	8.20	6.64	....	3.04
Grand Central River below the forks	14.6	....	8.36	5.84	....	4.25
Grand Central River below Nugget Creek	39	....	....	[a] 4.42	....	3.36
Kruzgamepa River at outlet of Salmon Lake	81	7.05	....	3.20	5.63	3.05
Between Grand Central River below the forks and Kruzgamepa River stations	66	....	....	2.62	....	2.79
Nome River at Miocene intake	15	3.43	2.71	3.36	4.29	....

[a] Approximate.

TABLE 3.—*Minimum flow of streams in Seward Peninsula.*

STREAMS RISING IN FOOTHILLS.

Stream.	Elevation.	Date.	Minimum flow.	Drainage area.	Minimum run-off per square mile.
	Feet.		*Sec.-feet.*	*Sq. miles.*	*Sec.-feet.*
Iron Creek below mouth of Canyon Creek	450	Aug. 14	17.1	37	0.46
Eldorado River below mouth of Venetia Creek.	400	....do	44	51	.86
Jett Creek	800	Sept. 10	[a] 4.2	1.4	3
Copper Creek	800	Aug. 11	.8	.85	.94
Nugget Creek	785	June 28	[b] .96	2.1	.46
David Creek	590	Aug. 19	3.3	4.3	.77
Dorothy Creek	500	Aug. 18	2.9	2.7	1.1
Hobson Creek	500	July 4	10.5	2.6	[c] 4
Slate Creek (tributary of Stewart River)	700	Aug. 19	2.2	2.1	1.05
Stewart River	400	....do	11.4	36	.32
Penny River	120	Aug. 1	[a] 36	19	1.9

[a] Lowest measurements obtained. The flow was less on certain dates.
[b] The lowest flow later in the season was 3.0 second-feet, or 1.4 second-feet per square mile on August 11.
[c] The flow of Hobson Creek is from large limestone springs whose catchment area may not coincide with the surface drainage basin.

STREAMS RISING IN KIGLUAIK MOUNTAINS.

Stream.	Elevation.	Date.	Minimum flow.	Drainage area.	Minimum run-off per square mile.
Grand Central River (North Fork)	750	July 1	23	5.4	4.3
Grand Central River (West Fork)	850	Sept. 15-17.	19	5.4	3.5
Grand Central River below the forks	690	Sept. 16-17.	47	14.6	3.1
Grand Central River below Nugget Creek	455	....do	90	39	2.3
Between Grand Central River below the forks and station at Nugget Creek.	....	....do	43	24.4	1.76
Crater Lake outlet	925	Sept. 15-17.	3.1	1.8	1.7
Thompson Creek	720	Sept. 16-17.	5	2.5	2
Windy Creek	650	Aug. 3	32	12	2.7
North Star Creek	900	Aug. 10	2.9	2.3	1.26
Sinuk River	770	Aug. 3	20	6.2	3.2
Buffalo Creek	800	....do	9.1	4.4	2.1
Nome River	575	Aug. 5	20	15	1.3
Fox Creek	550	Aug. 16	17.3	11	1.6
Crater Creek	550	Sept. 16-17.	39	....	....
Kruzgamepa River	442	Aug. 19-Sept. 17.	175	81	2.16

RAINFALL.

In connection with the stream gaging, four rainfall stations were established, as follows: Nome, claim No. 15, on Ophir Creek, foot of Salmon Lake, and Deering. Records were received only at the first three stations, where the mean monthly rainfall was as follows:

Mean monthly rainfall, in inches, at stations on Seward Peninsula, 1906.

Station.	June.	July.	August.	September.	Total, June to August	Total, June to September
Nome	Trace.	2.38	2.50	1.02	4.88	5.90
Salmon Lake	Trace	4.92	3.33	3.26	8.25	11.51
Ophir	Trace.	3.57	1.91	([a])	5.48	....

[a] No record.

The following statement gives briefly the climatic conditions existing in this area during the years 1899–1906:

1899. July, four rainy days; August, fourteen rainy days; September, fourteen rainy days; recorded at Teller.

1900. June and July, warm and dry, tundra fires common; August to end of September, rain.

1901. June to August, inclusive, cold and foggy with some rain; September and October, usually clear and cold with one or two hard rains of a few days' duration.

1902. June, dry; July, ten rainy days; August, six rainy days; September, three rainy days; recorded at Teller.

1903. Summer warm; little rain, but considerable fog.

1904. June, dry; rainy days as follows: Ten in July, ten in August, ten in September; temperature moderate.

1905. Very wet and cold the whole season.

1906. Very warm and dry; tundra fires common; maximum temperature 85°.

THE CIRCLE PRECINCT.

By Alfred H. Brooks.

INTRODUCTION.

The gold-bearing area tributary to Birch Creek, in the central Yukon region, is usually known as the Birch Creek district.[a] Birch Creek lies, for the most part, in the so-called "Circle precinct," which embraces the Birch Creek and Preacher Creek basins, as well as Woodchopper and other small gold-bearing streams. This whole region is tributary to the town of Circle, which is located on the west bank of the Yukon and contains several hundred inhabitants.

Means of communication are very inadequate throughout this region. Freight is delivered at Circle or other points by steamer in the summer and during the winter months is hauled to the various placer mines, distances varying from 10 to 50 miles, at a cost of 3 to 6 cents a pound. Wagon roads are almost entirely lacking, and during the wet weather of the summer the horse trails become wellnigh impassable. A system of wagon roads is the first need of this region. The difficulties of communication are also rendered greater here than in some of the other inland placer districts by the entire absence of telegraph or telephone lines.

In spite of the adverse conditions, the Birch Creek district stands to-day as one of the few placer camps which have been developed entirely without the aid of outside capital. Since the discovery, in 1894, step by step, through the efforts of the miners who have taken their capital out of the ground, advances have been made. Though this is one of the last of the Alaskan mining fields to be invaded by capital, this change is now in progress, for during 1906 several groups of claims passed into the hands of strong companies. This will eventually revolutionize mining methods and bring about a great increase of production. As the installation of mining plants will require several years, however, the production meanwhile will decrease.

The following notes are based largely on the writer's own observations during a journey in 1906 along the Yukon and through the Birch Creek district, which occupied about a month, but free use has

[a] "District" has no legal significance as a territorial subdivision, for the units are officially known as precincts.

been made of the publications of Prindle,[a] who has already described the general features of the geology and topography, and these will not be redescribed except so far as is necessary to an understanding of the description of the placers. The uniform courtesy and hospitality shown to the writer throughout the region greatly aided the investigation.

STATISTICS.

Data in regard to the gold production of this region are exceedingly scant, but the following estimates are based on the best evidence available. The error in the tables may be as great as 10 or 15 per cent.

Approximate value of gold production of Birch Creek district, 1894–1906.

1894	$10,000	1902	$200,000
1895	150,000	1903	200,000
1896	700,000	1904	200,000
1897	500,000	1905	200,000
1898	400,000	1906	300,000
1899	250,000		
1900	250,000		3,560,000
1901	200,000		

Estimated value of gold production of Birch Creek district, by creeks.

Deadwood Creek [b]	$700,000
Mastodon and Mammoth creeks [b]	2,060,000
Eagle Creek [b]	600,000
Other creeks [b]	200,000
	3,560,000

The first three areas in the foregoing table continue to be the largest producers, probably in about the ratio of total output there given. Of less present importance, but also productive, are Harrison, Miller, Greenhorn, Woodchopper, and Fourth of July creeks. Gold has also been found on a number of other streams which have yielded only a small production and are too numerous to mention. It is estimated that values have thus far been found along a total length of 23 miles, but it is impossible to state what proportion of this pay streak has been worked out. There are but few claims in the entire district that have been entirely worked out, and, in fact, even these will, to a certain extent, probably be reworked by improved methods. In 1906 there were about 200 men at work in the district on about 60 to 100 claims.[c] Most of the mining was by pick and shovel methods, but one small hydraulic plant was operated on Harrison Creek and another with a steam scraper on Mastodon Creek. There were also

[a] Prindle, L. M., The gold placers of the Fortymile, Birch Creek, and Fairbanks regions: Bull. U. S. Geol. Survey No. 251, 1905; Description of the Circle quadrangle (one of a series on the Yukon-Tanana region): Bull. U. S. Geol. Survey No. 295, 1906.

[b] With tributaries.

[c] Claims are 500 feet long in Birch Creek district.

a number of steam bucket hoists. Winter work is now usually done with the aid of steam thawers.

The placers here to be described fall into two groups that differ both geographically and geologically—(1) placers lying within the Birch Creek basin and (2) those along streams which discharge directly into the Yukon. The gold of the first group is derived from mica-schist and quartz-schist bed rock; that of the second group is, in part at least, derived from a conglomerate, where it is of secondary origin.

BIRCH CREEK BASIN.

GENERAL GEOLOGIC FEATURES.

The known auriferous portion of the Birch Creek basin embraces primarily those streams which head in an irregular northwest-southeast trending ridge, of which Mastodon (4,500 feet) and Porcupine (4,900 feet) domes form the highest summits. The radial arrangement of the gold-bearing streams from this watershed is a striking feature and is suggestive of the location of a zone of mineralization.

Schistose quartzite and mica schist form the prevailing bed rock throughout the area. Locally these rocks are found to be feldspathic, and these phases may be altered intrusives, but for the most part the formations appear to be of sedimentary origin. The rocks are closely folded and much sheared, and the prevailing strikes are east and west. Granite intrusives are not uncommon. Notably on Deadwood, Mammoth, and Miller creeks there are considerable areas of this rock. The central parts of the intrusives appear to be massive, but along some of their margins the writer observed evidence of deformation. Whether this is generally true he was unable to determine. Prindle has described some diabase dikes which occur in this region, but none came under the observation of the writer.

A general wide distribution of vein quartz is attested both by the bed-rock exposures and by the character of the fluvial deposits. This quartz is very frequently found to be iron stained, and one naturally turns to it to seek a source of the placer gold. There is but little direct evidence on this point. The presence of pyrite-bearing vein quartz in the auriferous alluvium is a characteristic feature of these deposits. On Eagle Creek a 4-foot gold-bearing quartz vein is said to have been encountered in the drift mining, but the writer did not see the exposure, as the drift had caved in. A specimen of the quartz showed it to be iron stained and broken by thin seams of gold. The gold of the adjacent placer was angular and carried much quartz. A mineralized fracture zone about 8 inches in width has been found on the upper part of Deadwood Creek. Within this zone the schist is permeated by stringer veins

carrying pyrite and galena, and it is reported to carry values of $6 in gold and $8 in silver.

Spurr[a] reported the finding of gold-bearing quartz on Harrison Creek. He describes the occurrence as follows:

> The best example of gold-bearing quartz found in the gravel is a rhomboidal block of quartz schist, about 4½ by 5 by 2 inches, found on claim 91, on North Fork, about three-quarters of a mile above the forks. On one of the larger surfaces of this block is a quartz vein which is richly spotted with flakes and specks of gold, ranging from three-sixteenths of an inch in diameter to mere specks, which finally become invisible to the naked eye.

These facts indicate that the placer gold is derived from zones of mineralization in the schist series. The wide distribution of the placer gold is not a favorable indication that the values are sufficiently localized in the bed rock to afford commercial ore bodies. It must be said, however, that there is little evidence on this point, and workable lodes may yet be found when a systematic search is made.

The alluvium, like the bed rock, varies in character. Nowhere was any foreign material observed in the stream gravels, and as a rule there is a progressive increase in size of material toward the headwaters of any given watercourse. Where mining operations have been carried on the extreme depths to bed rock usually do not exceed 20 to 30 feet and probably do not average more than 8 feet. In most sections the material becomes very angular toward bed rock. The bed rock itself is in general deeply weathered, and the material excavated usually includes 2 or 3 feet of it. Along nearly all the creeks one or more benches occur on the valley slopes. Those that have been found to carry values are from 2 to 20 feet above the present stream floors. The character of the alluvium on the benches is similar to that of the valley bottoms, but much of it is deeply buried under talus, or "slide rock," as the miners call it. This talus has in many places so obscured the original topography that the benches are not found until they are developed by mining excavations. At several localities the writer observed still higher benches, 40 to 50 feet above the present stream floors, but these appear to be very local, and even if found to be auriferous are beyond the reach of the present water supply.

A feature repeatedly observed in this province by Prindle is the asymmetrical character of the valleys when viewed in cross section. One wall is usually steep, with benches entirely absent, while the other has a gentle gradient and is broken by numerous benches. The miners have taken cognizance of this fact in their prospecting, which has been devoted chiefly to the gentle slopes where the old channels and benches, if present, would be preserved.

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[a] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 353-354.

The gold-placer deposits vary so greatly as to dimensions that few general statements can be made. In fact, the width and the thickness of the pay streak vary according to the cost of extracting it. For example, if values of $2 to the cubic yard are the lowest that can be profitably mined, as is probably the case with present usage in mining throughout most of the district, it puts a limitation on the dimensions of the pay streak quite different from what it would be if the costs were reduced to $1 per cubic yard. It is therefore very difficult to make any broad statement relative to the pay streak.

Throughout the gold-bearing region the alluvium can be said to be auriferous, inasmuch as it usually carries enough colors of gold to be found by the ordinary methods of panning. On the other hand, the pay streaks as now mined (i. e., with a probable minimum value of $2 to the cubic yard) are confined to certain creeks and to certain channels in the creek floor or on the benches. With these limitations it is probably fair to state that the pay streaks do not average more than 40 or 50 feet wide through the district, though on some creeks, notably on Mastodon, a width of over 200 feet has been mined at a profit. Probably few single pay streaks are traceable for more than 1,000 or 2,000 feet, though a succession of them may give practically a continuous zone of placers for several miles.

The same limitations must be placed on any statement in regard to thickness. Gold may be distributed through the entire thickness of gravels, but appears to be more commonly concentrated in the 2 or 3 feet next to bed rock. It is usually found to a varying depth in the weathered bed rock. In general it appears to be true that where the gravels are well rounded the gold is more uniformly distributed than where the material is angular, but in the first case the values per cubic yard are likely to be less.

Most of the rich pay streaks have a lenticular form, with their longer axes parallel to the trend of the stream valley. The pay streak may be straight or may wind from one side of the valley to the other. It is more likely to be straight in the broader valleys than in the smaller ones. If the valley is asymmetrical, the pay streak may be crowded to the steep wall by the talus which comes down the gentle slope. The talus may also bury an older channel.

In distribution the gold follows the same general law as the gravel, being coarsest at the points farthest upstream and gradually becoming finer downstream. The several exceptions to the rule noted only prove that the gold has in some places a very local source, being probably derived from mineralized zones which cross the drainage courses.

The average value of the gold of the Birch Creek basin, as reported by operators, is $17.73 per ounce, the Eagle gold being the purest and Deadwood the most impure.

Prindle has described the various creeks in detail, and it will not be

necessary here to repeat the descriptions. A few notes on development will, however, be appended. Harrison Creek w ll be described in more detail, as it has been developed since Prindle's studies were made.

NOTES ON DEVELOPMENT.

BIRCH CREEK.

The bars along Birch Creek have been found to be auriferous and were, in fact, the scene of the first discoveries of gold in the district. During low water some gold has been taken out of these bars with the aid of rockers. The wide extent of these deposits, their probably unfrozen condition, and the absence of bowlders have attracted the attention of those seeking dredging ground. It should be noted, however, in considering this form of deposit that the richness of the bars is not a criterion of the gold contents of the deeper alluvium. In the river bars the gold is in a concentrated form, and the balance of the alluvium may be almost barren. As there has been no excavation to bed rock in these large streams nothing is known of the depth of the alluvium or the values in it. Extensive prospecting with churn drills should precede the installation of dredges.

DEADWOOD CREEK.

One hundred and six 500-foot claims have been staked on Deadwood Creek and more or less work has deen done on 67 of these. Gold has been found in commercial quantities from a point about a mile above the mouth throughout the length of the creek, a distance of nearly 9 miles. One considerable tributary, Switch Creek, has also yielded values. Nearly all the mining on Deadwood Creek has been carried on by small operators and by simple methods. Many a prospector who has been on the creek since its discovery has never attempted to gain more than a living wage from his holdings, and the creek can be called a stronghold of conservatism.

In the lower mile of its course the Deadwood Creek valley broadens out and gradually merges with that of Crooked Creek, and here the values are more disseminated than they are above and, therefore, are not susceptible to profitable exploitation by the crude hand methods. This part of the field is worthy of careful examination by those looking for dredging ground. Though it may be unsafe to predict the probable conditions to be encountered, yet the following suggestions can be made. It is very likely that the bed rock is slabby quartzite schist or soft mica schist, with possibly some granite. Probably the values are considerably disseminated, and it is not to be expected that the gold will be coarse. The alluvium will probably be found to be made up chiefly of well-rounded gravels, and it is, therefore, quite possible

that there are considerable areas of unfrozen ground. There is no measure of the thickness of the alluvium below a point one-half mile above the mouth of the valley, where it was only 10 feet to bed rock. However, it does not seem probable that the bed-rock floor slopes more than 25 feet to the mile, and, therefore, it is not to be expected that the alluvium will be found to be more than 35 feet thick.

Among other improvements which will undoubtedly come is the working of large groups of claims instead of individual holdings. There is no doubt that if the entire creek could be worked by one company there would be a great economy in costs and a greater percentage of the values could be recovered. There appears to be little hope of obtaining water outside of the basin, but the creek itself furnishes an adequate supply in most seasons for at least one large operation.

The gold output for 1906 is estimated to have been about $120,000 in value, less than 50 per cent of which was taken out by winter drifting. It is estimated that 11 claims were worked during the winter by 35 men and 13 claims during the summer by 60 men.

BOULDER CREEK.

Though the gravels of Boulder Creek are auriferous, as would be expected, for it lies in the gold-bearing zone, yet so far the only placer values found have been on a small tributary called Greenhorn Creek. Here the gravels are only 4 feet deep, but although they carry good values, the lack of water often prevents mining during much of the open season.

MAMMOTH CREEK.

Mammoth Creek, which is formed by the junction of Independence and Mastodon creeks, has a broad flood plain, being 100 to 500 yards wide. The bed rock is probably chiefly schist, but in part granite. The granite yields some large bowlders; the schist is as a rule deeply decomposed. The bed-rock floor slopes at a very low angle. The alluvium is probably 10 to 15 feet deep, and is made up of rather well-rounded material, much of which is frozen. In the excavations, bowlders of 2 to 2½ feet are not uncommon, and some 3 to 4 feet in diameter were observed. The gold is reported to be fine and its distribution fairly uniform. Mammoth Creek has not been the scene of much mining except at its head and about halfway to its mouth. At the latter place a small steam shovel was installed and a pit of about 6,000 cubic yards capacity excavated some years ago. This was an experiment and the results are said to have been satisfactory to the operators. In 1906 the creek was under examination by dredging men, who seem to be justified in considering this dredging ground.

INDEPENDENCE CREEK.

Considerable gold has been taken out of Independence Creek, but during the last year there were only a few operators at work. At its mouth the valley floor is about 100 yards wide, but narrows rapidly in going upstream. The pay streak appears to be irregular and swings from one side of the creek to the other. The gravels are from 3 to 9 feet deep. There are some well-defined benches along the creek. In 1906 some work was done at half a dozen claims on this stream, but the aggregate output was small.

MASTODON CREEK.

Mastodon Creek contains the richest gravels yet discovered in the district and has been by far the largest producer. The bed rock is practically all quartz and quartz-mica schist, with many quartz veins. At the mouth of the creek the valley floor is about 400 yards in width and gradually narrows down to about 200 yards 2 miles above. The lowest 2 miles of the valley are the richest and contain the largest pay streak, which is about 200 feet wide and 7 to 10 feet thick. In this part of the creek there are well-defined benches some of which have yielded rich placers on the northwest valley slope. About 2 miles from the mouth the walls are steep and apparently have no benches, while the pay streaks are narrower and not so thick.

A part of the alluvium on Mastodon Creek is frozen and therefore could not be dredged unless the ground were first thawed. There are, however, considerable areas that are not frozen. The tailings from former mining operations probably contain enough gold to pay for rehandling with a dredge. The grade of the major portion of the stream is 100 or 200 feet to the mile.

Mining was actively pushed throughout the greater part of the creek during 1906. Most of the operations were by shoveling into sluice boxes, but several steam hoists and one small hydraulic plant with steam scraper were in operation. It is reported that considerable property changed hands during the year preparatory to more extensive operations.

MILLER CREEK.

Miller Creek, though never a large producer, has been worked more or less continuously since 1895. Its bed rock is chiefly schist, similar to that of Mastodon Creek, but the evidence of mineralization is not so strong. The gravels vary from 12 feet in thickness near the mouth to 4 or 5 feet near the head. The pay streak varies from 2 to 6 feet in thickness and 20 to 40 feet in width. The grade of the stream is about 150 to 200 feet to the mile. In 1906 mining was carried on in a small way at half a dozen localities.

HARRISON CREEK.

Gold was found on Squaw Gulch, a tributary of Harrison Creek, as early as 1894, and considerable work was done on the main stream up to 1896. As no high values were found, Harrison Creek was nearly abandoned for the richer placers which promised better returns. It is only within the last two years that the problem of working these relatively low grade deposits has been seriously considered.

The creek has two forks called North and South, on both of which gold has been found, but only the former is now being developed. One of the first discoveries of gold in the basin was at Pitkas Bar, at the junction of the two forks.

The writer visited only the upper 4 miles of North Fork. Here the valley floor is 200 to 300 yards wide, with flat bottom and steep slope on the south side. On the north the valley rises more gently and is deeply covered with talus. There are no excavations in this slope, and while no topographic evidence of benches was noted, it seems not impossible that they may exist beneath the slide material. Farther downstream the valley gradually contracts and is said to narrow down to a steep-walled canyon before it joins South Fork. The valley of South Fork is somewhat broader and appears to be more symmetrical. From the junction of the forks the valley continues to broaden until it merges with the Birch Creek valley 12 miles below.

The bed rock on North Fork is probably chiefly quartz-mica schist, but the occurrence of some granite pebbles in the alluvium indicates the presence of that rock within the basin. The writer saw very few bed-rock exposures, but the character of the alluvium indicates that the schists are cut by numerous quartz veins, many of which are stained with iron, indicating mineralization. A slab of schist cut by a gold-bearing quartz vein found near the forks has already been described.[a]

Just above the canyon the bed rock is said to be 20 feet below the surface. From 6 to 7 miles above, near Discovery claim, the writer observed a depth of 8 to 9 feet to bed rock on the north side of the valley and near the center, but only 3 or 4 feet near the south wall. A mile or more upstream the bed rock was found to be 8 to 12 feet below the alluvial floor. In this part of the valley the grade of the stream is probably about 75 to 100 feet to the mile, and that of the bed-rock floor is approximately the same. Although no accurate data are available, the reconnaissance maps indicate about the same grade throughout this basin. Naturally the grade decreases near the mouth and in the canyon it is probably much steeper.

[a] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 353-354.

The alluvial floor of the valley varies in width, but is about 300 feet wide at Discovery claim, and probably this is not far from an average for the two forks. Below the forks, as has been indicated, the valley is much wider. Well-rounded gravels characterize the alluvial deposits so far as seen by the writer. Bowlders of more than 2 feet diameter are uncommon, though some of 3 feet were observed. Much the greater part of the material is schist, with some quartz and a little granite. The gravels are well stratified, are loose, and so far as known are not frozen. It is this fact which has prevented the creek being thoroughly prospected, because the water flows in the gravels throughout the year.

There is little turf or muck on the gravels, and the whole section is in most places made up largely of sand and gravel. The bed rock is usually weathered and is broken by seams of clay, a secondary product, but so far as seen by the writer there is no well-defined stratum on the bed rock at the base of the gravels.

The gravels of both forks are known to be more or less auriferous. At a number of localities some gold has been mined by pick and shovel methods, but the values so far as determined are not high enough to make this a paying proposition. It is reported that as high as $5 a day has been made on this creek. It appears that the values are rather evenly distributed, both horizontally and vertically. There is, however, a marked concentration in the lower 3 to 5 feet of the gravels, and much of the weathered schist carries gold to a depth of 1 to 2 feet. The gold is fine, flaky, and bright colored. The largest nugget reported, with a value of $4, was found on the upper part of the creek. There has not been sufficient prospecting to determine the value of any considerable body of gravel. While 5, 10, and 30 cent pans are reported from bed rock, these, of course, can not be considered as average values. Near the Discovery claim thirteen pans taken from gravel near bed rock are said to have yielded about $1 worth of gold. Considerable garnet and pyrite occur with the concentrates.

At the time of the writer's visit only two groups of claims were being developed. In the lower group, embracing several claims near Discovery, a dam had been put in, with a view of ground sluicing and thus concentrating the values, which are subsequently to be shoveled into sluice boxes. A small hydraulic plant has been established on another group of claims, embracing No. 3 to No. 17 above. The gravels here are 8 to 12 feet thick, and the tailings are handled by a small elevator. Water is brought from the creek above through a flume 2,700 feet long under a head of 100 feet. This plant was erected in the fall of 1905, and was run for a short time in the fall and again in the early summer of 1906. At the time of the writer's

visit in August the dry weather had caused a shortage of water, and the mine was not in operation.

Harrison Creek, with its thawed gravels and dissemination of values, would seem to be worthy of investigation by those looking for ground to be mined by steam shovels or dredges. The bed rock, so far as known, is soft and could be taken up by a dredge. Bowlders appear to be absent and the gravels are of a fairly uniform size. As it would require 3 or 4 feet of water to float a dredge it might be necessary to use steam shovels, which would considerably enhance the cost of installation and operation.

EAGLE CREEK.

Gold was discovered on Eagle Creek as early as 1895, but the wave of Klondike excitement, which carried many miners out of the country, retarded its development for several years. Since 1901 much profitable mining has been done on this stream.

Eagle Creek has two forks. The northern, called Miller Fork, does not appear to carry values, but on the southern, called Mastodon Fork, placers have been found. The main stream has a gravel-floored flood plain 100 to 400 yards wide, but the tributaries flow through V-shaped gulches. The bed rock appears to be chiefly schist, with an abundance of quartz.

The alluvium varies from 8 to 20 feet in thickness. Of this 5 to 15 feet is muck. The gravels are subangular, but are fairly well stratified and carry considerable clay. The bottom layer is usually made up of 1 or 2 feet of sticky clay. The gravels are not frozen below the surface and water circulates through them all winter. The grade of the stream is reported to be about 100 feet to the mile. The pay streaks are 4 to 8 feet in thickness and vary from 30 to 80 feet in width. In some places parallel pay streaks have been mined. Much of the gold is coarse and it has a bright color, with higher value than any other of the district.

Mining has been carried on for about 2 miles along the main creek and half a mile up Mastodon Fork. A large part of it has been done by drifting in winter. Though the pay streaks are rich, the cost of operating, in view of the fact that all drifts had to be timbered, has been great. It is reported that during the winter of 1905–6 about 25 men were at work on the creek. Recently a large group of claims has been bought up on this creek, and it is reported that a company contemplates working them by dredging methods.

OTHER CREEKS.

Besides those described above gold has been found on a number of other creeks, which have yielded very little. None of these were visited by the writer except Twelvemile Creek, where no values have

been found. On this stream the bed rock is made up of a slabby quartzite, together with schists. Twelvemile Creek has a broad flood plain, but nothing is known of the depth of gravels, though they do not appear to be deep. Other streams in this part of the Birch Creek basin are said to carry auriferous gravels. A little mining has been done on Porcupine Creek, a tributary of Crooked Creek near the mouth of Miller Creek. The valley of the stream is wide and the gold in the gravels appears to be much disseminated. The gravels are said to be 12 to 15 feet thick. Some excitement was caused during 1906 by the discovery of gold on Portage Creek, a tributary of Medicine Lake, in the southeastern part of the Birch Creek basin. Though about $200 worth of gold was said to have been taken out of one claim, further prospecting failed to reveal any values.

At various times gold has been reported in the Preacher and Beaver Creek basins, but the presence of values has never been established. These basins appear to lie outside of the gold-bearing area, though details in regard to the geology are meager.

CREEKS TRIBUTARY TO YUKON RIVER.

GENERAL GEOLOGIC FEATURES.

The influx of prospectors in 1898, following the discovery of the Klondike, led to considerable prospecting along the streams tributary to the Yukon between the boundary and Circle. So far as known no placers have ever been found in the streams of this region entering the Yukon from the north. Mission and Seventymile creeks are referred to on page 38, and the present discussion will be confined to Washington, Fourth of July, and Woodchopper creeks, together with some smaller streams.

So far as known to the writer the gold that occurs on these streams is from a different formation than that found in the Birch Creek basin, and in at least one place it has its source in a conglomerate. Therefore the character and extent of the deposits are probably different from those of the placers above described. It must be admitted, however, that the evidence at hand is too incomplete to permit definite assertion in regard to the bed-rock geology of much of this belt.

The rocks exposed along the Yukon between Eagle and Circle do not anywhere include any of the older schists, such as are associated with the Birch Creek placers. In fact, over much of this belt the formations are slightly altered limestones, shales, slates, and conglomerates, which do not bear evidence of mineralization and will not attract the placer miner. Locally, however, some of these rocks are mineralized and contain more or less gold. Thus on Nugget Gulch,

a tributary of Washington Creek, slates of Cretaceous age are found which are permeated with quartz veins, some of which must yield gold, as the associated alluvium is auriferous. The writer was not able to study this locality, but it appears that the coarse gold occurs in small patches on the bed rock. This occurrence, though probably of small commercial import, has a far-reaching significance, as it indicates that there has been an intrusion of mineralized veins since these younger rocks were deposited. The writer is, however, of the opinion that this mineralization is not general enough to encourage the search for placers where these Cretaceous slates form the country rock.

The occurrence of gold in the conglomerate has an entirely different significance. There appears to be a fairly well defined belt of conglomerate running parallel to the Yukon from Seventymile Creek to Birch Creek, near the big bend. Both in the Seventymile basin and on Woodchopper Creek placers have been found which must have derived their gold from this rock. Therefore the conglomerate must, in part at least, be auriferous.

This conglomerate was probably laid down in Tertiary time, after the mineralization of the older rocks, and its gold content is comparable to that of the present placers. Such auriferous conglomerates have long been known in the Yukon region, having first been noted by Spurr,[a] who termed them "fossil placers." There is no evidence that the conglomerate itself carries sufficient value to pay for milling, though this is not impossible. The fact that the associated placers are only of moderate richness argues against any considerable values being found in the parent rock.

Much of the conglomerate is only loosely consolidated and weathers so readily that it is easily mistaken for high bench gravel. As a result prospectors sometimes assume that it marks an old river channel and expect to find very rich leads. Though it is not impossible that the conglomerate represents the deposit of an old watercourse, it by no means follows that such a deposit would be any richer than the placers of the present stream. The term "old channel" has a very alluring sound to those who are familiar with the occurrence of gold in California. Even if this conglomerate should locally be found rich in gold, only such parts of it as are decomposed could be mined by placer methods. Therefore the gold in it, except where it has served to enrich present streams, has now no commercial significance.

The double concentration which must have taken place while the gold of these placers passed from its original source in the bed rock through the conglomerate and into the alluvium of the present streams is favorable to the formation of rich placers, yet none have

[a] Spurr, J. E., Geology of the Yukon gold belt, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 365-366.

been found. This is probably due in part to the fact that the conglomerate itself carries no great values and in part to the fact that much of the conglomerate has not been affected by erosion and therefore the gold in it has not been re-sorted.

The placers to be described here have little in common, and therefore few general statements can be made. So far as they have been opened up, neither high values nor extensive pay streaks have been found. It is by no means impossible that somewhere in the conglomerate belt erosion has found a rich layer in the conglomerate and that more valuable placers have been formed than any thus far discovered.

These placers have the advantage of being more accessible than most of those in the Yukon basin. Most of them are not over 10 or 15 miles from steamboat transportation on the Yukon. As they lie in the lower parts of the plains of considerable streams, they could probably be reached with water carried in ditches, provided there is a sufficient body of auriferous gravel to warrant the outlay.

NOTES ON DEVELOPMENT.

FOURTH OF JULY CREEK.

Fourth of July Creek was not studied by the writer. The best information obtainable indicates that the bed rock is limestone and slate with some conglomerate. The gold is said to have its source in the conglomerate. The deposits are reported to be from 10 to 20 feet thick, 6 to 15 feet being made up of muck and 4 to 5 feet of gravel, of which 3 feet is said to carry values. The gold is flat, fine, and bright colored. The largest nugget was valued at $2.25. As a rule the bed rock is deeply weathered. One bench is reported to carry values, but the relations are obscured by the abundance of slide matter.

A trail 10 to 12 miles long leads from Nation, on the Yukon at the mouth of Fourth of July Creek, to these placers. Though many claims have been staked and considerable prospecting done, the ground thus far productive is limited to a small group of claims. The total output since the discovery in 1898 is estimated at between $25,000 and $30,000 in value. Plans are said to be under foot looking toward larger operations in this field. It is reported that half a dozen men were at work here in 1906.

WASHINGTON CREEK.

GOLD.

Washington Creek flows through a northward-trending valley, whose floor is from half a mile to a mile in width. The bed rock for the lower 3 miles of the creek is black slate or shale of Cretaceous age.[a]

[a] Collier, A. J., Coal resources of the Yukon: Bull. U. S. Geol. Survey No. 218, 1903, pp. 28-32.

Farther upstream the creek cuts a greenstone and chert formation, probably of Devonian age, and 10 miles from the Yukon it crosses another belt of Cretaceous slate, which forms the bed rock in Nugget Gulch, a small southerly tributary. These rocks are succeeded to the south by a broad belt made up of a Tertiary conglomerate, sandstone, and shale series, which contains some lignitic coal seams. This belt of coal-bearing rocks has a width of at least 10 miles. Still higher up the valley older rocks are said to occur again.

Placer gold has been found at two localities in the Washington Creek basin—(1) in Nugget Gulch, about 9 miles from the Yukon, and (2) on Surprise and Eagle creeks, about 10 miles above. The placers on Nugget Creek consist of very much localized accumulations of coarse gold on bed rock. Values are so irregularly distributed that it is questionable whether they can be mined at a profit. The gold appears to have its source in the Cretaceous slates, and it is worthy of consideration at least whether the mineralization of the bed rock is not sufficiently localized to pay the cost of extraction. The upper locality was not visited by the writer, but from the best accounts the gold here appears to be derived from a conglomerate. The value of the total production of Washington Creek does not exceed a few thousand dollars.

COAL.

Washington Creek has been the scene of some ill-advised attempts at coal mining. Though there is considerable lignite in the basin, much of the money spent in development has been wasted on experiments in transportation rather than in testing the seams as to extent and quality. The coal openings are from 10 to 14 miles up the creek, and as the seams exposed appear to be of no better quality or greater thickness than others which lie much closer to the Yukon, the outlook for profitable exploitation is not hopeful. The seam examined by the writer, about 14 miles from the river, occurs in friable sandstone and shales, striking about east and west and dipping 30° N., and showed the following section. The exposure is on the north side of the valley, about 40 feet above the stream level.

Section of coal seam on Washington Creek.

	Ft.	in.
Roof, soft blue-gray shale.		
Shaly lignitic coal	2	6
Clay	0	2
Shaly lignitic coal	2	0
Bone parting	0	2
Good lignitic coal	1	0
Clay	0	5
Good lignite	1	0
Clay shale	0	1
Impure coal (lignite)	0	3

	Ft.	in.
Clay shale	0	2
Coal (lignite)	1	4
Clay shale	0	2
Lignitic coal with some partings	2	0
Clay shale	0	3
Impure lignitic coal	1	0
Good coal (lignite)	0	1
Clay shale	4	0
Good lignitic coal with bone partings	1	4
Clay shale with some bone partings	4	0
Covered, but probably no coal.		

The coal carries considerable sulphur. On burning it produces many clinkers. The ash has a reddish tinge. The following is an analysis of a sample taken from this same district a little lower down the creek:

Analysis of coal from Washington Creek.[a]

Water	13.48
Volatile combustible matter	43.74
Fixed carbon	39.68
Ash	3.10
	100.00
Sulphur	.24

The remarkably low percentage of ash suggests that this sample was taken from one of the minor seams and was not an average of the entire section exposed. Such a grade of coal could probably only be secured by hand picking after mining.

During 1905 and 1906 a company attempted to establish a winter transportation system to the Yukon by the use of a 100-horsepower traction engine, which was expected to haul five sleds, each of 10 tons capacity. While such a scheme might be feasible with a good roadbed, it proved entirely impracticable without one. This plan involves the storage of the coal hauled in winter for consumption during the summer months—a doubtful experiment, because the lignite slacks readily after being exposed to the air.

In spite of the adverse conditions of mining and low grade of coals in this field, it shares with other fields of the Yukon a prospective value. There can be no question that with the present increase in the demand for fuel and the rapid destruction of the forests the time is not far distant when the Yukon lignites will play an important part in the commercial development of the inland placer districts.

COAL CREEK.

Coal Creek, together with its tributaries, Sam and Colorado creeks, which have yielded a little placer gold, was not visited by the writer, but to judge by the juxtaposition to Woodchopper Creek, it appears

[a] Collier, A. J., Coal resources of the Yukon: Bull. U. S. Geol. Survey No. 218, 1903, p. 31.

probable that the conditions of occurrence of the placers are about the same. Apparently, however, from the reported discovery of a galena-bearing quartz vein on Colorado Creek, all of the basin is not underlain by conglomerate. It is not known to the writer whether this vein carries values or what its dimensions are.

Three or four claims are said to have been worked in this basin during 1906. Most of the gold is said to have been taken from bar diggings in the main creek.

WOODCHOPPER AND MINERAL CREEKS.

Woodchopper Creek, which is about 12 miles long, enters the Yukon from the west, about 30 miles above Circle. Its flood plain is about half a mile in width, and the alluvium is probably 8 to 15 feet deep. Five miles from the Yukon, Mineral Creek, the scene of some placer mining, joins Woodchopper Creek from the south. The floor of the Mineral Creek valley is 100 to 150 wide, and the slopes are broken by benches. Woodchopper Creek has a gradient of about 100 feet to the mile. Remnants of benches are to be seen along the creek, the highest of these being marked by the ridge on the northwest side, which is flat and slopes toward the Yukon.

In the lower mile of Woodchopper Creek only massive greenstones were observed. Above these is a belt of black slate and limestones about a mile wide that continues nearly to the mouth of Mineral Creek, where it is succeeded by friable conglomerates in a belt said to be several miles wide. Chert and quartz pebbles dominate in the conglomerate, which is only imperfectly consolidated and outcrops in few places. This fact often leads to its being mistaken for bench gravel by the prospector.

So far as known the gold-bearing alluvium is confined to those creeks that cut the conglomerate, which, therefore, appears to be the source of the gold. Mineral Creek and its tributary, Alice Gulch, are the only streams which have thus far been found to be productive. Prospects are reported from Grouse and Iron creeks.

At the mouth of Mineral Creek the alluvial floor of the valley is about 75 yards wide, but narrows upstream. A mile upstream, at the mouth of Alice Gulch, it broadens out again into a basin about 75 yards wide. On the south wall of Mineral Gulch three well-defined benches were observed, having altitudes of about 20, 150, and 250 feet above the creek.

Muck is encountered on some claims to a depth of 30 feet; the gravels underneath vary in thickness from 2 to 5 feet and are made up chiefly of well-rounded quartz and chert pebbles. The pay streak lies in parallel channels 12 to 14 feet wide, as many as three of these channels having been found in a width of 80 feet. The pay streak under present systems of mining is from 1½ to 4 feet in thickness.

A varying amount of bed rock is taken up, depending on its looseness. Apparently gold occurs in bed rock beyond the depth to which it can be profitably extracted. The bed rock appears to be chiefly conglomerate, but in some places a plastic clay which may be a weathered shale interbedded with the conglomerate has been encountered. Prospectors report that the values are found in the conglomerate but appear to be absent in the clay. The conglomerate bed rock is invariably iron stained, where found under the placers. Gold has been found in the lower benches of the creek, but the higher benches have not been prospected.

The gold in the creek bed is usually bright colored, but that of the benches is dark. Most of the gold is coarse, the largest nugget having a value of $30. The value of the gold as reported by the miners is $19.09 to $19.30 per ounce, which would make it the highest of all found in the Yukon province. Values of 5 to 50 cents to the pan on bed rock are reported, but there are no data available for the average tenor of the pay streak.

Though Mineral Creek was staked as early as 1898, actual mining did not begin until several years later. In 1906 eighteen men were engaged in mining on this creek and more or less work was done on seven claims. Most of the work was by "shoveling in" methods, but one small hydraulic plant was used for stripping and three steam hoists were operated. Most of the mining was done in winter with the aid of steam points. The total production for 1906 is estimated to have been $18,000, of which four-fifths was taken out in winter.

THE BONNIFIELD AND KANTISHNA REGIONS.

By L. M. Prindle.

INTRODUCTION.

The northern foothills of the Alaska Range have been widely traversed by prospectors since the establishment of Fairbanks as a permanent supply point. In 1903 gold-placer mining commenced in the Bonnifield country, about 60 miles south of Fairbanks, and during 1906 the Kantishna region, about 150 miles southwest of Fairbanks and 30 miles north of Mount McKinley, was an area of considerable activity. These regions had produced, respectively, about $30,000 and $175,000 in placer gold. The writer and C. S. Blair, field assistant, were detailed to investigate the placers and also the deposits of lignitic coal of Cantwell River, which were visited by the Brooks party in 1902.

The sketch map (Pl. IV), with the foot traverses of the party in the two regions added to the topographic map made by the Brooks party in 1902, shows the geographic relations. The two most prominent geographic features of the entire area are the Alaska Range and the Tanana Flats.

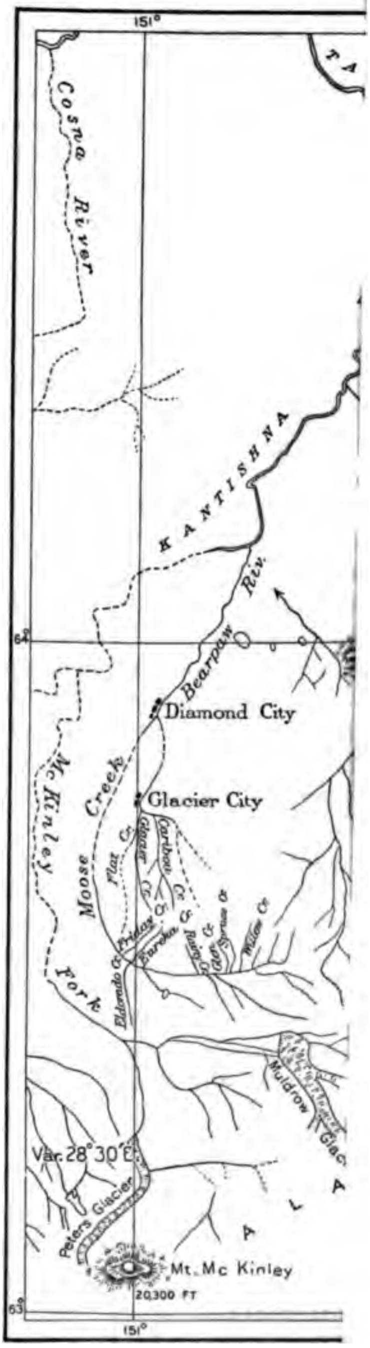
The Alaska Range in this part of Alaska trends round from the northeast toward the east and is composed of lofty alpine ridges, surmounted here and there by beautiful peaks. Minor ridges flank the main range on the north and their outer members descend with more or less abruptness to the level of the Tanana Flats. All the drainage is to the Tanana. The main drainage lines are northward, transverse to the ridges. Many of the upper valleys are gorged with glaciers and the lower valleys are a succession of narrow canyons interrupted by east-west valleys parallel to the ridges.

The Tanana Flats extend northward from the base of the foothills to Tanana River. They have a width in the area under consideration of about 30 miles. They widen rapidly toward the west, as the river flows northwest and the mountains recede to the southwest, and form an impressive foreground to the mountains. The flats absorb small streams from the foothills and the surface is drained by swampy creeks, which cross them irregularly. The larger streams, a

few miles after leaving the hills, meander sluggishly in no well-defined valleys and enter the Tanana with sloughlike inconspicuity. The surface is sparsely timbered with small spruce, tamarack, birch, and aspen, with a larger growth near the major streams and along the base of the foothills. Swampy areas flecked with lakes are interspersed with patches of birch where the ground is bare and dry, and the traveling therefore fairly good. Feed is good along the water-courses but during the long hot days of summer there is scant relief for the pack animals from the horseflies and mosquitoes, which render an otherwise friendly area a place of almost constant torment.

The bed rock of the Bonnifield and Kantishna regions includes highly metamorphosed ancient rocks and loosely consolidated deposits of comparatively recent origin. The most common distinction made by the miners is that between hard and soft bed rock, and this distinction is warranted by the conditions. The ridges are formed for the most part of metamorphic schists and igneous rocks; the intervening longitudinal valleys, of deposits in the main unconsolidated but older than those of the present streams. The most important fact from an economic view point is the distinction between the two groups of hard and soft bed rock. The hard bed rock from south to north includes a belt of highly metamorphosed schists, predominantly quartzitic schists with a small amount of interbedded crystalline limestone, and some carbonaceous schists; a belt of black slates with quartzite and cherty beds; and a belt of metamorphosed porphyritic feldspathic rocks. The belt of quartzite schists forms most of the bed rock in the Kantishna region, crosses Cantwell River just south of Healy Creek, and extends northeastward to the south of the Bonnifield region; the slates occur in the high ridges at the head of the Totatlanika and the porphyritic feldspathic schists form the several ridges to the north. These porphyritic schists occupy large areas in the northern foothills of the Alaska Range. They were observed throughout the area between Cantwell and Wood rivers. To the south they are interrelated with the black slates containing quartzite beds that succeed the quartzite schists. To the north they form the outermost ridges overlooking the Tanana Flats. Throughout this area are several prominent east-west ridges of these rocks rising 1,500 to 2,000 feet above the valleys that separate them. The color ranges from dark-gray to white. The prevailing tone is whitish, from the weathering of the large amount of feldspar that the rock contains, and much kaolinic material has been contributed by this rock to the deposits that occupy large areas in the longitudinal valleys between the ridges. The rock ranges in character from a coarsely porphyritic sericitic variety with feldspars 4 dm. or more in diameter to a fine, evenly grained white or gray sericite schist with no grains visible to the eye. These rocks are of igneous origin

U. S. GEOLOGICAL SURVEY



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and comprise highly metamorphosed rhyolitic rocks with probably some associated tuffs.

The soft bed rock includes thick beds of slightly consolidated sands, clays, fine gravels, and many beds of lignite, all overlain by thick deposits of gravel. Some of these deposits, at least, are of Tertiary age, and a more detailed description of them will be found in the section on the coal deposits (pp. 221–226).

BONNIFIELD PLACER REGION.

GENERAL DESCRIPTION.

The region known as the "Bonnifield country" is named for John E. Bonnifield, who was one of the first men to locate in this part of Alaska. The name referred originally to the region immediately west of Wood River, but as prospectors explored valleys farther west the name came to be used in a broader sense, and for the purposes of this report includes all areas of placer mining between Wood River and the Cantwell, 50 miles farther west.

The region is difficult of access in summer. The waterways are not easily navigable, even for small boats, yet supplies are sometimes brought in them about 40 miles upstream to points a dozen miles or more from the hills, whence they are transported overland by man or horse power about 20 miles to the creeks where they are to be used. Pack trains are occasionally taken over the flats along the west side of Wood River, but this method is expensive. Most of the supplies are transported during the winter, when streams afford good traveling for dog or horse sleds and the time consumed from Fairbanks to the creeks where mining is in progress is but a few days.

The region is delimited on the south about 20 miles south of the flats by prominent eastward-trending ridges which overlook it. The area between these ridges and the flats contains several ridges approximately parallel, with altitudes of 4,000 feet and intervening spaces a few miles in width at a level 2,000 feet below that of the ridges. Isolated prominences like Jumbo Dome form important landmarks and the area is one of diversity.

THE CREEKS.

The most striking characteristic of the drainage and one that finds explanation in the different conditions that once prevailed is the fact that the streams in general have cut canyons in ridge after ridge in their northward progress toward the flats. These canyons are for the most part narrow, and talus from the overtowering cliffs obstructs the streams. The intervening parts of the valleys are in general open, and gravel plains up to 1,000 feet or more in width have been developed.

The gravels include angular bowlders from the hard bed rock, finer material of the same nature, and a large proportion of well-washed gravels, in the main rather fine, which have been derived from the unconsolidated deposits that occupy large areas in the longitudinal valleys.

The creeks on which most work has been done are Totatlanika with its tributary Homestake; Grubstake, Roosevelt, and Hearst creeks, tributaries of the Tatlanika; and Gold King Creek, which flows independently out of the hills into the flats.

TOTATLANIKA CREEK.

Totatlanika Creek is comparable in size to streams of the Yukon-Tanana country like the Chatanika. It is formed by the union of several tributaries which originate in a high schist ridge to the south. It flows northward toward the flats, cutting canyons in several ridges of the igneous schist, and has developed in the intervening spaces tributaries that drain large areas in which the hard rocks are largely covered with coal-bearing deposits.

Mining was being done at scattered localities on the main creek along a distance of about 6 miles and on Homestake Creek, a small tributary. The conditions on the main creeks at all the localities are similar. The stream flat attains a width in the more open parts of the valley of several hundred feet, and the grade of the valley is approximately 100 feet to the mile. The quantity of water varies greatly. At ordinary stages on a rough estimate there are perhaps a dozen sluice heads available, and for the most successful working, by the methods employed, a low stage of water is desirable. The gravel bars at low water are mostly bare, and it is there and in the stream bed that the mining is being done. The bed rock includes hard, blocky porphyritic feldspathic schist with some associated carbonaceous schist and abundant quartz veins. A belt of andesitic rocks crosses above the mouth of Homestake Creek. The gravels are derived from these varieties of bed rock and from the unconsolidated coal-bearing deposits, which supply many vein-quartz and chert pebbles, pieces of lignitic coal, and a few large bowlders of the granite and greenstone that occur in the uppermost beds of these deposits. The thickness of the stream gravels where work is being done ranges from 3 to 6 feet.

The gold is found in most places scattered through the gravels, but in others is confined to the surface of the bed rock, and where this is blocky is generally found to a depth of 3 feet or more within it. The gold is mainly flat and most of the pieces are less than a quarter inch in diameter. Occasionally pieces are found worth 25 cents, and a $2 piece was the largest noted. It is all well worn. Pay has been found over widths of 50 to 100 feet, with values up to 1½ ounces per day to

the man, but too little work has been done to give definite information regarding the average dimensions, values, or persistence of the pay streak.

Mining is done by open cuts in combination with wing dams. The ground is for the most part free from frost, and the only trouble from this source has been experienced in constructing bed-rock drains. Wing dams are used to deflect the water from the ground that is being worked, and water for sluicing is carried from the dam a distance of a few hundred feet to the sluice boxes. These are given a grade preferably of 9 inches to the box. There is but little sediment in the gravels and no dump boxes are used.

The timber available for sluice-box lumber in this part of the valley is limited, and lumber is packed 5 to 25 miles from the lower canyon in the winter. About a dozen men were working on the creek during the summer of 1906.

HOMESTAKE CREEK.

Homestake Creek is a small stream, about 4 miles long, which enters Totatlanika Creek in the uppermost canyon. The valley consists of two parts of different character. The upper part is open and flat—hardly more than a depression in an undulating, well-nigh timberless area several miles wide—that extends east and west between the ridges. The lower part is a deep canyon with vertical walls of andesite that crowd the stream to a narrow, crooked course and burden it with great fragments. The grade of the upper valley is approximately 100 feet to the mile; that through the canyon is over 200 feet to the mile. The amount of water carried by the stream is, during a dry season, insufficient for mining purposes. The bed rock of the upper valley is composed of unconsolidated clay and sand of the coal-bearing formation; that of the lower valley is the igneous rock of the canyon.

Most of the mining has been done at the upper end of the canyon and in the open part of the valley half a mile farther upstream. The deposits that are worked range from 2 to 6 feet thick. Gold has been found in 2 to 3 feet of gravel, and part of it is coarser than that of Totatlanika Creek, one piece worth $15 having been found. All of the gold apparently is well worn. The stream heads in gravels and above the canyon has not yet cut down to hard bed rock, and it would seem that the gold has been derived from the gravels.

There are but few trees in the upper valley. Sluice-box lumber and even firewood are packed from the main stream. Some of the ground prospects well, but so little work had been done that the possibilities of the creek were not definitely known. Unlike those on the main stream, successful operations on Homestake Creek are dependent on abundant rainfall.

TATLANIKA DRAINAGE.

About 10 miles east of Totatlanika Creek is the Tatlanika, formed by the union of Sheep and Last Chance creeks. This is a somewhat larger stream and has developed for itself in the section of the valley under consideration a gravel plain several hundred feet wide, with a grade of about 90 feet to the mile. A finely preserved bench 40 feet high and half a mile or more wide limits the stream on the west, and 3 miles to the west high gravel hills separate the Tatlanika drainage from the headwaters of Buzzard Creek; on the east are blunt terminations of low, broad ridges that separate the small tributaries entering from that side—Grubstake, Roosevelt, and Hearst creeks, on which most of the mining is being done. These enter in the downstream order given, the mouths being separated by distances of 3 miles and 1 mile, respectively. The creeks are similar in size and character, and gold occurs on all of them under about the same conditions and with apparently the same origin. The Tatlanika in this area has not yet cut down to hard bed rock and these minor streams have cut narrow valleys for themselves in the unconsolidated gravels, clays, and sands of the coal-bearing deposits. Grubstake Creek heads along the contact of the schistose bed rock and the soft deposits and is the only one of the three that has the hard bed rock within its drainage basin.

GRUBSTAKE CREEK.

Mining on Grubstake Creek is confined to a mile of the lower valley. The stream is 200 to 300 feet below the steep inclosing slopes of soft material and the stream flat is 150 to 300 feet wide. The grade is approximately 100 feet to the mile. At the lowest stage the creek carries approximately a sluice head of water. The bed rock is sticky clay, sand, and coal, all three distinct from the stream deposits. The thickness of the gravels that are being mined ranges from a few inches to 6 feet. These gravels include both fine and coarse material, with a small proportion of bowlders. They are made up of schist, vitreous quartzite, compact conglomerate composed largely of chert pebbles, vein quartz, chert, granite, and diabase; the amount of sediment in them is small.

Gold is found scattered through about 2 feet of gravel or confined mostly to the surface of the clay bed rock. The pay streak has a width of 25 to 75 feet, but outside of 25 feet is reported to be patchy. The coarsest piece found was worth $1.43 and the gold is valued at $17.35 an ounce. The common variety is composed of small flat pieces, all well worn. Mining is done by open cuts. In some places a few feet of the top gravel are stripped off, but generally all the material from surface to bed rock is shoveled in and the character of gravel and bed rock is such that 6 cubic yards a day per man can be handled.

The black sticky clay which forms the bed rock, after being cleared of the stream gravels, contains considerable gold which has settled into its surface or been trodden into it in the progress of the work, and experience has shown that the best way of saving this is to strip off a thin layer one-fourth inch or more thick, leave it in the sluice boxes over night with a small amount of water running over it, and in the morning stir it with a sluice fork. The loosened mass then easily yields up its gold. The boxes are set on a grade of 8 or 9 inches to the box. The lumber for mining purposes is brought from the lower canyon of the Tatlanika, a distance of 14 miles. Some mining was done during 1905 and half a dozen men were at work during 1906.

ROOSEVELT CREEK.

The lower part of the valley of Roosevelt Creek is rather open and is covered with a light growth of small spruce. The mining area is about 2½ miles above the mouth, where the valley is narrow. The bed rock is sticky clay and yellowish sand that belong to the coal-bearing formation. The stream gravels are similar to those of Grubstake Creek and are derived from the thick bed of gravels that caps the sands and clays. They are shallow and gold occurs in 1 to 1½ feet of gravel over a width of 20 to 60 feet. The gold is small, flat, and well worn, the coarsest piece found being worth about 45 cents. At the time the creek was visited there was insufficient water for sluicing. The gold has most probably been concentrated together with the stream gravels out of the thick gravel deposits in which the creek originates. A point to be emphasized is that the soft clays and sands which form the bed rock are just as truly bed rock to the stream gravels that overlie them and carry the gold as if they were hard rock. A thickness of several hundred feet of these unconsolidated deposits may overlie the hard bed rock and any attempt to sink through them to the solid formation would be not only a most difficult task, but, inasmuch as the only run of gold known overlies them, would be in all probability useless.

HEARST CREEK.

The conditions on Hearst Creek are similar to those on the other two streams. In the lower part of the valley the creek meanders deeply in a narrow canyon, exposing sections 100 feet thick of the unconsolidated light-colored, cross-bedded sands and fine gravels of the coal-bearing formation. These deposits in places have been benched and capped with stream gravels. The upper part of the valley is more open and the stream heads in the thick gravel beds that overlie the sands and clays. The only work that has been done is at a point about 2 miles above the mouth, where in 1905 a few thousand dollars were reported to have been mined. In 1906 this locality was being prospected.

GOLD KING CREEK.

Gold King Creek is about 8 miles east of the Tatlanika. The stream heads in hard bed rock and flows through a V-shaped valley sunk to a depth of 1,200 feet below the inclosing gravel ridges. Long, flat, tonguelike spurs extend from these ridges into the narrow stream flat. The grade is about 100 feet to the mile, and the quantity of water at the lowest stage is approximately three sluice heads. The bed rock at points where mining is in progress is clay. The gravels include the same varieties as are found on the other creeks, and the proportion of bowlders 3 feet or more in diameter is large. They lie scattered through the gravel and have acted as efficient riffles in retaining the gold. The thickness of the gravels that are being mined ranges from 4 to 8 feet. In some places gold is found in 4 to 5 feet of gravel; in others it is mostly near the clay bed rock. Generally about 2 feet of overburden are ground sluiced off and from 1½ to 4 feet shoveled into the boxes. The gold is flat; there are many pieces over one-fourth inch in diameter, and the coarsest piece was worth $1.25. This gold is said to assay $17.82 per ounce. Some of the ground is reported to yield about 1½ ounces to the shovel. All the work is done by open cuts, and the presence of so many bowlders retards the work. Shoveling in can begin in some seasons about the first of June. During the season of 1906, however, on account of the extent of glaciers in the creek work did not begin until June 20. The gold, like that of the other creeks, probably originates in the high gravels, and these are reported to carry prospects in many places far above the creek and even on the surface of the high, flat ridges. About a dozen men were working on the creek, and wages were $6 and board per day.

SUMMARY.

The creeks of the Bonnifield region may be divided into two classes—those that have, in a part of their valleys at least, cut into hard bed rock, and those that are still cutting their valleys entirely in unconsolidated deposits, including gravels, sands, clays, and coal beds. The greatest part of the gold has in all probability been derived from the thick gravels. The form of its occurrence in these thick deposits is unknown. It may be regularly distributed through them, it may be confined to some particular stratum in which it is spread broadly, or it may occur as a more or less clearly defined pay streak. The material of the gravels is all found in the ranges to the south. The gravels were deposited under conditions much different from those of the present time and are probably mixed in their upper part with some glacial material.

The only general test of the values that these gravels may contain thus far available is that afforded by the gold found in the gravels of

the present streams. Although fair pay has been found in places on some of the creeks, it would seem that if the high gravels carried noteworthy values the placers derived from them would be much richer than they have yet proved. All the work has been accomplished on a small scale under adverse conditions. Most of the mining is being done above the timber line. The work is hampered and in some places brought to a standstill by lack of water. The soft nature of the bed rock in some of the creeks means a tremendous amount of material that clogs the work and complicates the situation caused by lack of water. In general it may be said that the quantity of gold is not such as to overshadow the economic factors of water supply, character of bed rock, presence or absence of bowlders in the gravels, timber resources, and transportation, but that in every case these are the determining factors in the situation.

KANTISHNA PLACER REGION.

GENERAL DESCRIPTION.

The rich shallow diggings discovered in the Kantishna region in 1905 were found to be more local than at first supposed, and the results of 1906 were unequal to expectation. During the fall of 1905 there was much travel by steamer from Fairbanks. Passengers and freight were carried at $40 a piece and $50 a ton, respectively, and landed at Roosevelt, on McKinley River, or at Diamond, 60 miles above the mouth of the Bearpaw. The town of Glacier also was established 12 miles from Diamond, at the mouth of Glacier Creek, about midway between the steamer landing at Diamond and the placers of Glacier Creek. During the winter of 1905-6 there was much travel between all of these places and the creeks, and the winter trail from Fairbanks up Cantwell River to the road house at the crossing and thence overland was also used extensively. The month of February found many already on the back trail. During the summer of 1906 the town of Roosevelt, situated as it was remote from the creeks across an 18-mile stretch of swampy tundra, became practically deserted, and in the fall the many empty cabins of Glacier and Diamond testified with depressing emphasis to the decadence from the activities of the previous year.

The Kantishna placers, about 30 miles directly north of Mount McKinley, are in an outlying ridge somewhat apart from the main range and separated from it by high bare hills, which form the foreground to this portion of the range. This ridge trends northeast and southwest, and its most prominent summits have altitudes of 4,000 to 4,700 feet. To the southwest it abuts against the foothills; to the northwest it descends abruptly to the level of long, flat slopes that extend for miles from the base of the hills into the extensive flats of the Kantishna Valley.

The slopes are deeply furrowed by narrow V-shaped valleys. The drainage on the south runs into Moose Creek, a stream that heads far back in the foreground of the mountains, flows close along the southern base of the ridge in a finely benched open valley, and finally cuts a canyon through the ridge to flow northward to the Bearpaw. The streams that drain the northern slopes have long lower valleys limited on either side by the edges of low tonguelike spurs.

The material of the ridge is for the most part a highly metamorphosed and closely folded quartzitic schist, with garnetiferous quartz-mica schist, carbonaceous schist, a small amount of interbedded crystalline limestone, and much greenstone, part of which at least is intrusive. This formation is like that at the canyon of Cantwell River. south of Healy Creek, and is the same in character as that of the Fairbanks region. The occurrence of gold also and the associated minerals are the same for the most part as in the Fairbanks region. The formation has in general a northeasterly strike. The foreground of the mountains to the east is formed of hornblende granite and granite porphyry and some dikes of granite porphyry occur in the schists. Small areas of the coal-bearing rock occur in the region and coal from a fork of Moose Creek is utilized to some extent for blacksmithing purposes. The extension of the schist area to the southwest has not been determined. Topographically it terminates apparently at McKinley River; to the northeast it is probably continuous with the schists of the Cantwell Canyon. The rocks of the Alaska Range to the east are in general black slates partly altered by contact metamorphism, greenstones, intrusive granitic rocks, and volcanics.

THE CREEKS.

The creeks head in open V-shaped areas formed by the convergence of two or more small tributaries. The lower parts of the valleys are narrow canyons. Where these join the main valleys benching becomes prominent and their deposits merge into the tremendous body of gravels that has been spread far and wide from the Alaska Range. This material is for the most part easily distinguishable from the schistose gravels of the creeks.

The creeks where mining has been done are located on both sides of the ridge. Named from east to west on the south side of the ridge, round the west end and eastward along the northern slope, they are as follows: Spruce, Glen, Eureka, Friday, Glacier, and Caribou.

SPRUCE CREEK.

Spruce Creek flows its last mile in the valley of Moose Creek. Above this part of its course for about 1½ miles the valley is narrowly V-shaped and then near the head becomes more open. The grade in the narrow

part is about 350 feet to the mile, and the amount of water carried at ordinary stages is about two sluice heads. The lower valley has a considerable growth of spruce in a narrow belt near the stream. The bed rock observed is predominantly quartzitic schist, with some carbonaceous and green schists. The only point where mining was being done is about 2½ miles upstream, above timber line and about 700 feet above the level of Moose Creek. The gravels at this point are about 3 feet thick and comprise quartzitic schists with a small proportion of green schist, carbonaceous schist, crystalline limestone, and vein quartz. Pay is found over a width of about 12 feet. The gold occurs mostly on bed rock and to a depth of 2 feet within it. Much of the gold is coarse, and the largest piece found was valued at $6.40. Some of it is rough and has quartz attached, and there is no reason to doubt its local origin. Three men were working at this locality. Their sluice boxes were made of lumber packed from Glen Creek and were set on a 10-inch grade.

GLEN CREEK.

Glen Creek is somewhat larger than Spruce Creek and is more deeply cut below the spurs that rise nearly 1,000 feet above it on either side. From the forks to the mouth, a distance of 3 miles, there is a grade of about 500 feet. The gravels are similar to those of Spruce Creek, being predominantly quartzitic schist, and where work is being done they range from a few inches to about 3 feet in thickness. In some places gold is found through 2 feet of gravel and at others it is all on or within bed rock. The width over which pay is found ranges from 30 to 150 feet and values have been reported of $20 to $100 to the box length, or approximately a maximum value of 65 cents to the square foot of bed rock, but their distribution is irregular. Much of the gold is coarse; several $8 to $10 nuggets have been found, and the largest piece discovered weighed over 3 ounces. A few garnets are found associated with the gold. At the time of visit most of the miners had left for the season, and it was reported that only about seven men would winter on the creek.

EUREKA CREEK.

Eureka Creek proved to be the best producer of the region. It is a small creek only about 5 miles long, flows southwestward in a deeply cut valley, and enters Moose Creek just below the point where the latter has turned northward through the ridge. The valley of Moose Creek at this point is a flat several hundred feet wide, and the creek itself, a powerful stream, swings round to the east and is cutting laterally into the bed rock just at the point where Eureka Creek enters. The valley of Eureka Creek has a grade of about 235 feet to the mile, and the smallest quantity of water flowing during the season of 1906

was reported to be two sluice heads. The bed rock is principally quartzitic schist, with some associated carbonaceous schist and greenstones. Small basaltic dikes were observed in a few places cutting the schists. Throughout most of the valley the stream gravels are composed of material derived from the bed rock, but in the lower part of the creek these rather fine subangular schist gravels become mixed with material derived from the heavy Moose Creek wash that rests on a bench over 150 feet vertically above Eureka Creek. In the process of downward cutting through which the drainage system has passed these bench gravels, comprising bowlders of granodiorite, greenstone, hard conglomerate containing chert pebbles, and metamorphic slates, all of these being materials mostly unlike those characteristic of the Eureka Valley, but entirely similar to those of the Alaska Range, have become intimately mingled with the local deposits.

Mining has been confined for the most part to 2 miles of the valley immediately above the mouth. The thickness of the deposits that are being worked ranges from 1 to 5 feet and the width is in most places that of the stream gravels, which is rarely more than 100 feet and in some places less than 20 feet. The gold is mostly on bed rock or within it to depths of 1 to 3 feet, but all the gravel from surface to bed rock is generally shoveled into the boxes. The richest ground was in the first half mile above the mouth, where many nuggets were found, the two largest of which were worth $186 and $678. Nuggets were not confined to this part of the creek, however, and some worth as high as $40 have been found 2 miles above the mouth. The nuggety gold is generally of a lighter color than the finer grade. The gold found in the upper part of the valley is mostly rough and gritty. Average assay values were reported ranging from $15 to $16 per ounce. The proportion of black sand accompanying the gold is small. Here and there pieces of stibnite occur in the gravels, and these have been derived, probably, like similar occurrences on Caribou Creek, from veins in the schists. The association in this respect is similar to that of the Fairbanks region.

The reason for the richness of the gravels near the mouth has often been a subject of inquiry and it might be supposed that a part of the gold at least was derived from the heavy Moose Creek bench gravels through which Eureka Creek has cut. So far as could be learned, however, these bench gravels are not known to carry payable values, and the explanation is rather to be found in the riffle efficiency of large bowlders in retaining gold that would otherwise be carried out from the smaller valley along with the finer wash. A decrease of grade of the smaller stream near the mouth may also be a factor.

All the gravels are worked by the open-cut method. Boxes are given grades ranging from 7 to 9 inches per box. There is but little

sediment in the gravels and no dump boxes were employed. The flats of Moose Creek opposite the mouth of Eureka Creek are covered with a light growth of small spruce and a few small spruce dot the steep slopes of the lower Eureka Valley, but lumber for mining purposes has to be brought from points 6 miles down the Moose Creek valley.

Gold was discovered on Eureka Creek in July, 1905. The richness of the gravels justified to a great degree the stampede that followed. The richest ground that has been discovered was mostly exhausted during July and August, 1906, when there were 50 or more miners on the creek. Wages during the busiest time of the season, when shifts were working night and day, were $1.25 per hour, paid in gold dust valued at $16 per ounce. There was a settlement of considerable size at that time on the flat of Moose Creek just above the mouth of Eureka Creek. A restaurant was in operation with rates for board alone of $4.50 per day, and there were small stores where supplies of various kinds were obtainable. About a dozen men were working in August, 1906. Various estimates of the output were reported, ranging from $150,000 to $160,000.

A small amount of work was done during the summer in the canyon of Moose Creek, about 5 miles below Eureka Creek, and some pay was reported.

FRIDAY CREEK.

Friday Creek is 2½ miles long and carries at the lowest stage about half a sluice head of water. The valley is cut to a depth of 1,500 feet below the inclosing ridges. The upper part where small streams unite is somewhat openly V-shaped; the lower part is very narrow and has a grade of over 400 feet to the mile.

Mining is confined to about a mile of the creek above the point where it emerges into the valley of Moose Creek. The bed rock includes quartzite schist, carbonaceous schist, greenstone, crystalline limestone, and dikes of granite porphyry. The gravels are formed mostly of these materials and are from 3 to 6 feet thick. Gold is found in 1½ to 2 feet of gravel and about the same thickness of bed rock. The gravels are in some places limited to the narrow space of 12 feet between the bed-rock walls; in others they reach 100 feet in width. Both nuggets and fine gold are found. The nuggets range in value up to $29. Many of them contain much quartz and are very rough, and some are rudely crystallized. Scattered pieces of galena several inches in diameter are found in the stream gravels, and one of these was assayed for the Survey and found to carry 184.76 ounces of silver and 0.20 ounce of gold to the ton. Only six men were working on the creek.

GLACIER CREEK.

It is about 8 miles round the base of the hills from Friday Creek to Glacier Creek. The latter is a larger stream than the other creeks that have been described, heads against them, and after emerging from its deep V-shaped canyon flows for several miles between broad, level-topped ridges before it joins the Bearpaw. Cabins were built at intervals along the entire length of the creek during the winter of 1905–6, but the area that up to the present time has proved most productive is a section of the valley about a mile long where the creek emerges from the hills into the area of long gravel-covered ridges. Near the end of the season of 1906 it was reported that pay was being found also on Yellow Creek, a small tributary near the head.

Glacier Creek, although considerably smaller than Moose Creek, is a powerful stream, and there has been no lack of water for mining purposes. The grade of the valley in the part that is being worked is approximately 130 feet to the mile. The bed rock observed comprised quartzite schists, greenstone schists, and garnetiferous mica schists, with abundant quartz seams and lenses. The gravels are coarse and the proportion of bowlders is large. The thickness of the deposits in the working area ranges from 2 to 5 feet, and the width in places is 250 feet. The gold is mostly on bed rock. The creek meanders sharply at its point of emergence from the hills, and the best pay is reported to have been found just above the points of the meanders. Values have been found ranging from $75 to $200 to the box length, and the gold is reported to be worth $16.40 per ounce. Many nuggets have been found, and the largest was valued at $365.

At the point where the stream leaves the hills there is a bench about 75 feet above the creek, capped by 3 to 5 feet of gravel underlying 6 to 8 feet of muck. Gold occurs in about 18 inches of the gravel and is yellower and flatter than the creek gold. Several areas of the bench gravels were reported to prospect, but insufficient work had been done to determine their values definitely. All the work was done by open cuts, and some of the lumber for sluice boxes was packed distances of 12 to 14 miles from Moose Creek. In the fall of 1906 there were approximately twenty men on the creek.

CARIBOU CREEK.

Caribou Creek is somewhat larger than Glacier Creek, but in other respects the conditions are similar. There is the same variety of bed rock and deposits, but up to the present time no well-developed pay streak has been found. In the early part of the season considerable work was done on Crevice Creek, a small tributary near the head. The gold was found to be rough and coarse, the largest piece being valued at $90. At the time Caribou Creek was visited by the Survey party but few men were working.

Stibnite (antimony sulphide) occurs in the wash of Caribou Creek, and a ledge containing this mineral has been located a short distance above the point where the creek emerges from the hills into the benched area of the lower valley. The creek forks at this locality, and on the southern fork, which has been named Last Chance, the ledge is exposed. The vein is about 4 feet thick, and the vein matter includes essentially quartz and stibnite. The quartz is partly massive and partly in the form of small crystals up to an inch in length. The antimony sulphide is in part a crystalline mass embedded in the spaces between the quartz crystals and in part a bluish-black, very fine-grained massive variety. The ledge strikes northeastward and dips 75° N. The country rock is hornblende schist, to the structure of which the vein conforms. A short distance upstream the hornblende schist is structurally conformable to the quartzitic schist. A small amount of work was being done here in the hope that the ledge material would be found to carry values. Of three specimens from this locality assayed for the Survey two contained silver at the rate of 4 and 2.76 ounces to the ton and the latter carried in addition 0.12 ounce of gold to the ton; the third specimen contained 0.12 ounce of gold, but no silver. Too little work had been done to give definite information regarding the proportion of the antimony sulphide in the vein, but pieces of nearly solid ore up to a foot in diameter were obtainable.

SUMMARY.

The Kantishna placers are in an area of crystalline schists. The gold-producing creeks head near each other. The bed rock of all the creeks comprises practically the same kinds of rock and the gravels are shallow. The bulk of the gold in every case has in all probability been derived from the valley in which it is found. The occurrence is not confined to any particular section of the valleys, but is such as to suggest a derivation from different points along them. The manner of its occurrence in the bed rock is indicated by the many pieces found in most intimate association with quartz, by a small flat nugget one-tenth of an inch thick attached to garnetiferous mica schist, and by the occurrence of silver- and gold-bearing galena and stibnite in the gravels of several creeks. Pieces of these sulphide ores a foot or more in diameter were observed in the gravels, and the fact that in one case high values in silver with some associated gold were carried by this material lends not only a qualitative interest to this occurrence but a quantitative one as well. The vein of stibnite on Caribou Creek, although carrying in the material tested no high values in silver or gold, illustrates the form of occurrence, and its interest is enhanced from the fact that the metal antimony, which forms about 70 per cent of the mineral stibnite, is at present (1907)

in considerable demand. Regarding the question whether there is sufficient high-grade silver ore or stibnite to pay for working, nothing definite can be said. It is probable that both the lead and antimony sulphides and the small amount of iron pyrites associated with them occur as small veins scattered through the schists. Although both stibnite and galena resemble each other to some extent, the former has often been determined by miners through its character of fusing readily in the candle flame. The coarser varieties can also be distinguished from galena by their lighter color and somewhat fibrous texture. The coarser varieties of galena break into little cubes.

There is a great resemblance between the Kantishna and Fairbanks regions. The geologic environment and mineral associations are practically the same. The essential difference is apparently one of physiographic development. The Kantishna region is in a youthful stage. The valleys are narrow and have steep grades, and their deposits are consequently shallow and have undergone less shifting with the accompanying gravitative differentiation of the heavy constituents to the vicinity of bed rock.

The bulk of the production has come from Eureka Creek and most of the remainder from Glacier Creek. The conditions on Eureka Creek probably find an explanation in the fact that the heavy foreign wash derived from the bench near the mouth, working in combination with a decrease in grade, checked to a greater or less extent the removal of the gold that was being brought down the valley of Eureka Creek while the canyon was being cut, and thus brought about an enrichment at this particular point. There is the possibility, too, that the bench gravels contributed a part of the gold. It is noteworthy in this connection that the richest ground on Glacier Creek is at the point where the valley emerges from the hills into the benched area that surrounds their base.

There was no lack of water during the summer of 1906, but in a dry season the small creeks would shrink below the economic limit. The timber resources in the vicinity of the hills are scanty. There is some fair timber along parts of the valley of Moose Creek and this increases in quantity toward the mouth, but in general the localities where mining is done are above the limits of good timber, and lumber has to be packed for several miles. The town sites of Glacier and Diamond were well timbered, and the valleys of the Bearpaw and Kantishna contain many small areas of fine spruce.

Steamer transportation during the summer of 1906 was very irregular, and the accessibility of the placers to the points where it is possible to land supplies from steamers is rendered difficult on account of swampy areas that in places well-nigh block the approaches to the hills. Up to the present time but little attempt has been made

to construct summer trails, as most of the transportation between the creeks and the local supply points has been done in winter.

The auriferous gravels thus far discovered are adapted only for summer work when sluicing can be done from about the 1st of June to the early part of September, and the rich ground first discovered has been largely worked out. There is some ground still remaining that contains fair pay, and about 50 men intended to remain during the winter of 1906-7 to prospect.

COAL DEPOSITS.

GENERAL DESCRIPTION.

Deposits containing lignite coal have a wide distribution in the northern foothills of the Alaska Range, but the only section to be considered here is that extending east from Cantwell River to Wood River, a distance of about 50 miles, and northward to the flats. The low spaces within this area between the east-west ridges of old metamorphic rocks are occupied by these deposits. They are for the most part but slightly consolidated, and have been so deeply incised by the drainage systems that in places nearly complete sections are exposed. That the present areas are only a part of masses formerly much larger in extent is shown by small isolated patches of these deposits that lie slantingly on the upper slopes of ridges and by well-worn pebbles derived from them that lie scattered on the tops of the highest ridges, 1,500 to 2,000 feet above the occurrences of the valleys. These deposits have been folded, the flexures being for the most part broadly open, with dips of 30° to 35°, but locally closer, with resultant vertical dips attended in places by consolidation of the gravel beds to conglomerate; in addition, here and there parts of the deposits have been faulted.

The material comprises alternating beds of sands, clays, coal, and gravels that are divisible into three parts—an underlying white deposit composed of angular and some well-worn, subangular, fine quartz gravels, with a large admixture of kaolinic material where the bed rock is feldspathic, an intermediate member of yellowish cross-bedded sands and fine well-worn gravels, dark plastic clays, and coal beds, and an upper member composed almost entirely of gravels. The feldspathic schists produce by weathering a large amount of white clay and the quartz veins which in places in these rocks are very numerous furnish abundant quartz material, and these characteristics of the old bed rock have gone over into the basal members of the sediments. The transition from the decomposed products of the schists that still retain their structural position to the same materials in the overlying deposits is in some places strikingly exhibited. The

thickness of these underlying deposits was not determined, but one section was observed in which 100 feet of them was exposed. The sands and clays of the intermediate member are naturally less conspicuous than the underlying beds, but have in many places become indurated by the burning of the coal beds and baked to a conspicuous red color. The overlying gravels at the localities where their relations to the underlying deposits were observed, whether in horizontal or tilted strata, were found to be structurally conformable. They are characterized by a yellow color. They include both fine and coarse material, are well worn and well rounded, and the predominant constituents are white quartz and chert of various colors, principally black. There is a considerable proportion of metamorphic rocks and many pebbles of compact chert conglomerate. In the upper part of the gravels, in strong contrast with their medium- to fine-grained material, are locally many bowlders of granitic rocks and diabase and a few well-rounded bowlders of dense chert and quartzite conglomerates. The greatest observed thickness of these deposits was approximately 3,500 feet. The upper gravels constitute about half of the entire deposit.

Fossil leaves are observable nearly everywhere in the beds associated with the coal, but except where these beds have been baked by the burning of the coal the fossils are poorly preserved. The age of the coal-bearing member has been determined as Kenai. The age of the gravels has not been determined, nor is it definitely known that they are chronologically conformable with the underlying deposits, but they have been folded at every point where folding was observed, along with the underlying deposits. Where valleys have been extensively developed in these deposits bench gravels have in many places been laid down on the truncated edges of the older deposits, and where these older beds are horizontal the bench gravels are in apparent conformity with them, obscuring the relationship. It is probable that deposits of various ages since the Kenai, formed under varied conditions of sedimentation, occur in this area and that the coarse material in the uppermost part of the gravels owes its origin to glaciation.

Parts of the gravel members of these deposits are auriferous and have supplied the gold for the Bonnifield region. There is a marked resemblance between these coal-bearing deposits, with their thick beds of overlying gravels, and the Kenai beds of the Seventymile Creek area near Eagle, with their coal-bearing deposits and thick beds of conglomerate formed largely of the same kinds of material. These latter beds also, as was observed by Brooks in the Woodchopper Creek area during 1906, are auriferous.

LOCAL OCCURRENCES.

The most prominent exposures of coal are on Healy Creek and Lignite or Hosanna Creek. These localities have been described by Brooks.[a] In 1906 a large part of the coal-bearing area on Healy Creek had been staked as coal claims.

Healy and Lignite creeks are about 5 miles apart. The valley of Healy Creek near its junction with the Cantwell is limited on the south by a high schist ridge. A similar ridge separates the valleys of Healy and Lignite creeks, but the schist part of this ridge terminates about 3 miles from the Cantwell and its continuation is composed of the thick body of gravels with the underlying coal deposits, which along the Cantwell becomes continuous with the deposits of Lignite Creek.

HEALY CREEK.

The deposits extend about 10 miles up Healy Creek, in places running parallel with the creek and in places crossing it. In the lower part of the valley they dip north from the schists, on which they rest unconformably, at angles ranging from 25° to 35°. Toward the upper limit of the deposit folding has been closer and there are vertical dips. The stream flat of Healy Creek is about 500 feet wide, and in parts of the valley coal beds form the banks for distances of a quarter of a mile or more close to the water. The thickness of these deposits from their base to the under surface of the overlying gravels, which are approximately 2,000 feet thick, is about 1,500 feet and the coal beds aggregate about 230 feet. The nature of the deposits and the relation to them of the coals are shown in the accompanying section of the deposits at a point about 2 miles above the mouth of the stream. The coal thicknesses were measured with the tape; the thicknesses of the intervening beds are in part only approximate. This section probably does not give the total thickness of coal, because some beds in almost every section have been destroyed by fire. In this section seven beds were observed 20 feet or more thick, aggregating 175 feet, and sixteen thin beds higher in the deposit aggregating 55 feet. The lower beds are of better quality than the upper ones, which are shaly and contain much woody material. While the thick seams contain some interbedded foreign material, the proportion is apparently small. The following analysis was made in the laboratory of the Geological Survey and is taken from Brooks's report, already cited:

[a] Brooks, A. H., note Collier, A. J., Coal resources of the Yukon, Alaska: Bull. U. S. Geol. Survey No. 218, 1903, pp. 44–46.

Analysis of coal from Healy Creek.

Moisture	13.02
Volatile matter	48.81
Fixed carbon	32.40
Ash	5.77
	100.00
Sulphur	.16

Section on Healy Creek 2 miles above mouth.

	Feet.
Overlying sands, clays, and gravels	2,500
Coal	14
Sands.	
Coal	7
Sands.	
Coal (shaly)	2
Sands.	
Coal	8
Sands and clays with two thin beds of coal	75
Coal	5
Sands.	
Coal	20
Sands	100
Coal	25
Sands	100
Coal	24½
Sands and clays	50
Coal	40
Sands and clays.	
Coal (two beds)	3
White sands and gravels	75
Brown earthy shales	60
Coal	21
Covered	50
Coal	5
Dark shales and red sandstone formed by burning of the coal	10
Reddish sands with fine white gravel	20
Coal	6
Covered	100
Coal	10
Fine sandstone, white sand, and clay	15
Coal	2
Clay and nodules of sandstone	12
Alternating beds of sand and gravel	30
Clay, sand, and sandstone	15
Well-rounded gravel mixed with sand and clay	20
Clay and sand	4
Well-rounded fine wash of quartz and chert	100

Total coal, 230 feet.

LIGNITE CREEK.

In the valley of Lignite Creek, where the space between the hard-rock ridges is wider than in Healy Valley, these deposits extend from the schist ridge that limits the valley on the south to the base of Jumbo Dome, a distance of about 3 miles, and eastward till limited by the schist ridge at the head of the creek. They have been cut to depths of 1,000 feet or more by the many tributaries of Lignite Creek, which have steep grades and form where crossing the resistant coal beds waterfalls up to about 30 feet in height. These narrow cuts are clogged with masses of material from the sandy beds that break away in great blocks from the steep bluff above to form sand heaps at the bottom, and contain blocks of coal 20 feet or more in diameter.

The following sections were observed. The first is at a point about 6 miles above the mouth; the other section is about 3 miles farther upstream, near the headwaters and near the eastern limit of the occurrence.

Section on Lignite Creek 6 miles above mouth.

Overlying gravel.	Feet.
Thin beds coal alternating with sands and clays	250
Coal	18
Sand	10
Coal	1
Clayey sand	10
Sand, cross-bedded	100
Coal	15
Sands	100
Coal	8
Sand	75
Coal	32
Sandy clay	40
Coal	10
Sand	12
Coal	20
Sand, clay, and small amount of fine subangular quartz gravel	25
Coal (only the top of a bed exposed).	
Total coal, 129 feet.	

Section near head of Lignite Creek.

Overlying gravel.	Feet.
Coal (shaly)	8
Sandy clays	50
Coal	6
Clay	10
Coal	12
Sands.	
Coal	1
Gray sand and gravel, clayey toward top	40
Coal	1½
Friable clays	10

	Feet.
Clean sand	20
Coal	1
Sandy clays	2
Cross-bedded gray sands and fine gravels	50
Ferruginous sandstone	2
Coal	6
Thin-bedded sands	100
Coal	10
Sticky clay	25

Total coal, 45 feet.

The valleys of these two creeks contain a large amount of coal. The conditions for transportation in the absence of a railroad are bad. The Cantwell is an unnavigable stream and the locality is about 50 miles south of the Tanana. It would seem that if the developments in the Fairbanks region should justify it the energy of these coals might best be transported in the form of electricity. The distance across country to Fairbanks, about 75 miles, is well within the practicable limits of such an undertaking.

OTHER AREAS.

In the area to the east wherever these deposits are cut to a sufficient depth the coal-bearing beds are exposed. They occur on Coal Creek, a small tributary of Totatlanika Creek, where they are used to a slight extent by the miners, and on Mystic Creek, about 2 miles from Wood River, where two beds 20 feet and 12 feet thick were exposed in a section 80 feet high. They are reported to occur also east of Wood River. There are approximately 600 square miles of these younger deposits between Cantwell and Wood rivers. To what extent they are underlain by coal has of course not been determined. The coal-bearing beds, too, probably vary greatly in number and thickness and furthermore have been in many places burned. The continuations of the coal beds of Healy Creek outcrop on the west side of Cantwell River, and it is very probable that there is considerable coal between Cantwell and Toklat rivers. Coal occurs farther to the southwest in local disconnected areas, and in the Kantishna region is used to a small extent.

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CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 314.]

The publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress for distribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.
4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the ninety-fourth in Series A, the complete list of which follows (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

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MAY, 1907.

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TOPOGRAPHIC MAPS OF ALASKA.

The following maps are for sale at 5 cents a copy, or $3 per hundred:

Casadepaga quadrangle, Seward Peninsula; scale, 1:62500. T. G. Gerdine.
Fortymile quadrangle; scale, 1:250000. E. C. Barnard.
Grand Central Special, Seward Peninsula; scale, 1:62500. T. G. Gerdine.
Juneau Special quadrangle; scale, 1:62500. W. J. Peters.
Nome Special, Seward Peninsula; scale, 1:62500. T. G. Gerdine.
Solomon Special, Seward Peninsula; scale, 1:62500. T. G. Gerdine.

The following maps are included as illustrations of published reports, but have not been issued separately. They can be obtained only by securing the report.

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